The Royal Aeronautical Society

(FOUNDED 1866)

with which is incorporated The Institution of Aeronautical Engineers

No. 260. AUGUST, 1932. Vol. XXXVI.

PROCEEDINGS

SECOND MEETING, SECOND HALF, 67TH SESSION

The Second Meeting of the Second Half of the 67th Session of the Royal Aeronautical Society was held at the Royal Society of Arts on Thursday, January 28th, Mr. D. R. Pye, Member of Council, presiding.

The CHAIRMAN: He would like to express his regret at the absence of Mr. Fairey (the President), due to illness, because the question of range was one in which Mr. Fairey had interested himself specially and, indeed, had given a lecture on the subject before the Society not very long ago. It was to be hoped that the product of Mr. Fairey's and Messrs. Napier's genius would bring yet another record to this country before very long. The Secretary would send the President a message of condolence and wishes for his speedy recovery.

To achieve the maximum range really depended on three kinds of efficiency—the aerodynamic efficiency of the aircraft, the thermal efficiency of the engine, and finally, what might be called the human efficiency of the navigator. The last of the three might, in some circumstances, be the most important, but the knowledge which enabled a navigator to be efficient depended upon the second kind of efficiency, because it was according to the performance of the engine that one had to settle the question, for example, "Does it pay to fly high?" That question had been discussed a good deal, but the conclusions reached by the various theoretical investigators were necessarily as varied as their assumptions. Mr. Tizard, in his Wilbur Wright Lecture in 1924 said: "It is somewhat unfortunate that the conclusion that the air range of an aeroplane is sensibly independent of height has never yet been put to a satisfactory practical test." Some six years ago it was decided to put this question of the air range of an aeroplane under correctly-controlled conditions as a definite item of research on the Air Ministry Research Programme, and when they had listened to the paper that was to be given that evening, he believed it would be realised that it was a matter of great difficulty to get really reliable and accurate data on this problem. Therefore, it was a happy choice that the authors of the paper should have been chosen to undertake this investigation and he would like to associate with them the names of Flight-Lieut. Maitland, who was the pilot in much of the earlier work, and Mr. H. L. Stevens, who was the Chief Technical Officer at Martlesham throughout the trials. Flight-Lieut. Scroggs, who was pilot in the later trials, had had wide experience of testing work at Farnborough and at Martlesham and Mr. Woodward Nutt, a Scientific Officer on the Air Ministry Research Staff, had had experience during the last six years both at Farnborough and Martlesham, and more recently at Felixstowe.

SOME FACTORS AFFECTING THE RANGE OF AIRCRAFT WITH SPECIAL REFERENCE TO HEIGHT *

BY

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AND

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PART I.

Introductory

From that memorable day in December, 1903, when Orville Wright made the first power driven flight, aeronautical engineers have directed continuous efforts towards improving the range of aircraft. The distance covered on that first flight was about 120 yards. At the present time the record for distance flown in a straight line stands at 5,012 miles, and as for duration, some unfortunate Americans recently succeeded in staying in the air for nearly 27 days and nights without landing. This latter record has little value beyond that of an endurance test of the engine, and possibly the physiological effects on the occupants of the aircraft. The long distance record, however, has a direct influence upon the design of both military and commercial aircraft.

Range is directly or indirectly of the greatest importance to aircraft of all descriptions. For commercial aircraft range in itself is of some value, for it must be remembered that the main object of air transport is to travel long distances in a short time. Economy, which goes hand in hand with range, is of obvious importance as in any other commercial undertaking. A reduction in the fuel consumption of a given aircraft not only reduces the cost of the fuel for a given journey, but also enables a correspondingly greater load to be carried. For military aircraft, with an increase in range longer reconnaissances may be made, a greater load of bombs or troops may be carried a given distance, or a given load a greater distance. For the private owner an improvement in the range of his aircraft not only enables him to fly further, but also makes the cost of any given journey less.

Limitation and Improvement in Range

Apart from the question of refuelling in the air, which cannot yet be said to have progressed beyond the experimental stage, the range of an aircraft is limited by the load of fuel it can carry, and the fuel load is determined largely by the purpose for which the aircraft is designed. In this connection the curve given in Fig. 1 is of interest. It shows range plotted against the percentage of the fully loaded weight of the aircraft made up by the fuel for a large number of aircraft, ranging from light aeroplanes and single-seater fighters to aircraft specially designed for long distance flying.

Broadly speaking, there are two ways in which an improvement in range may be sought. The first is by improving the aerodynamic efficiency of the aircraft, and by so doing lessening the amount of work required to propel it through the air. The second is by improving the thermodynamic efficiency of the engine and so lessening the quantity of fuel required to do a given amount of work; in other words, ensuring that the fuel carried is used to the best advantage.

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Mr. C. R. Fairey dealt with the first method very fully in his paper before the Society in October, 1929,[1] and has, moreover, produced one of the aerodynamically most efficient aircraft ever built in the Fairey Long Range Monoplane. It is with some of the factors affecting the second method that the present paper is more directly concerned. At the same time it is emphasised that the authors are in no way engine experts, so that the opinions expressed are based primarily on a somewhat limited practical experience.

The Effect of Height

The question of the variation of the range of an aircraft with height is of the greatest importance when seeking long range or economy, as on it depends to a

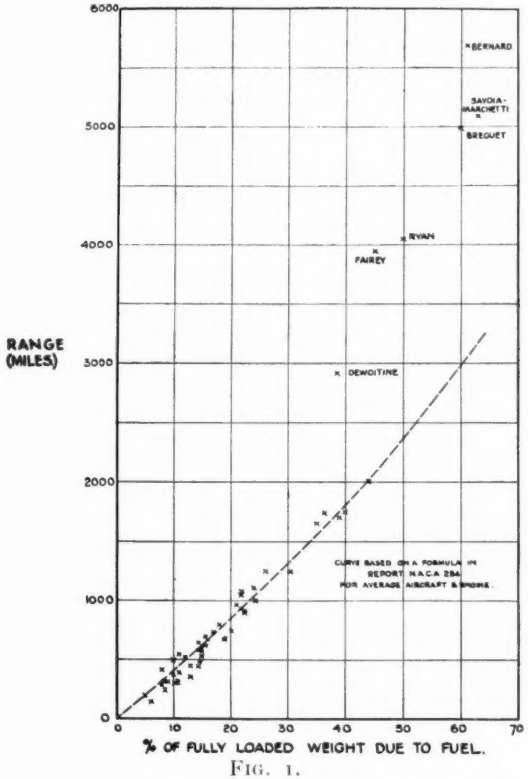


FIG. 1.

large extent the height at which any particular flight is made. In spite of this it is an aspect of the problem of range which has not received a great deal of attention until recently.

It should be said at the outset that wind is obviously a very important factor in determining the height at which to fly. The variation of wind speed with height is, however, a meteorological problem which does not come within the scope of the present paper, and although the effect of wind will be considered very briefly later, we are mainly concerned here with that familiar though rarely met phenomenon still air.

[1] Ref. 1.

Historical

For several years after the end of the War there was a very general impression—which seems to have been based on totally inadequate grounds—that it was very much more economical to fly high. Possibly the reason for this impression was the feeling that owing to the reduced air density at high altitudes less power would be required for propulsion than at ground level. This, of course, overlooks the fact that the power required depends on the true air speed and that the most economical speed varies appreciably with height.

Another reason put forward for this belief was that by climbing to a great altitude a certain weight of fuel would be consumed, and for the rest of the flight the aircraft would be lighter by this amount. The potential energy acquired on the climb could be used in part in a prolonged glide at the end of the flight. On a long flight, however, the saving due to this would be exceedingly small.

It seems much more probable that any foundation there was for this prevalent impression was largely due to bad carburettor design and inadequate control of the mixture strength at low altitudes. It is unlikely that it had any basis in current theory, for, as will be seen, those who had made a theoretical study of the subject came to conclusions as diverse as their initial assumptions.

As early as January, 1918, Mr. A. Berry went into the theory of economical flight,[2] taking into account the loss of weight due to consumption of fuel. Making certain initial assumptions he considered various methods of flying a given distance and came to the conclusion that for minimum petrol consumption the aeroplane must fly throughout at an attitude corresponding to its best L/D ratio. He also concluded that for maximum speed and minimum consumption of fuel the aeroplane should climb at full throttle to as great a height as possible, then fly level and throttled until it arrived at a point from which it could reach the objective in a glide with the engine off, all at the attitude of maximum L/D.

These conclusions, however, were based on the assumptions that the power of the engine was proportional to the relative atmospheric density and that the specific fuel consumption of the engine was constant for all throttle openings, and also on certain aerodynamic assumptions, none of which, as pointed out by Mr. H. Glauert at the time, were very close approximations to practice. The conclusions reached were therefore suspect.

In June, 1919, a report[3] was published in which Mr. Glauert made a further analysis of the conditions for economical flight. The method of treatment adopted was to determine the best method of flying an aeroplane whose aerodynamic and airscrew characteristics were fixed, but for which the speed, total load, and height of flight were taken as variables. Level flight only was considered, and the aerodynamic assumptions and the assumed variations of engine power with height, and of specific consumption with throttle opening all approximated more closely to actual conditions. One conclusion of this report confirmed that of Mr. Berry that there is a best attitude, which is independent of weight and height, at which the flight should be made. Another important conclusion was that to secure maximum range with a given load of fuel it is advantageous to fly at as great a height as possible, and that the most advantageous loading for a given aircraft is such that the height at which the flight is made is the greatest at which the aircraft can fly level at the attitude of maximum range.

Later, in 1919, a report[4] was presented to the National Advisory Committee for Aeronautics of the U.S.A. by Mr. J. G. Coffin in which the question of range was dealt with by two distinct methods. The first was quantitative, using performance estimates for a particular aircraft and assumed values for the specific

[2] Ref. 2.
[3] Ref. 3.
[4] Ref. 4.

fuel consumption of the engine at full throttle and when throttled, and in the second the subject was treated from first principles on theoretical grounds. The effect of the change in weight due to consumption of fuel was considered. The conclusions were reached that for maximum range in still air, flight should be made at an indicated air speed corresponding to the best L/D ratio, and that the height of flight had no material effect on the range.

In the Wilbur Wright Lecture of the Society in 1924[5] a theoretical argument was put forward by Lieut.-Col. H. T. Tizard to show that the range of an aeroplane in level flight at any indicated air speed should be practically independent of the height. Colonel Tizard went into the engine side of the question in some detail and pointed out that the range of an aircraft at a constant indicated air speed depends on the specific fuel consumption of the engine at constant torque. He showed that on a basis of engine theory and extensive test bench experience it was unlikely that this would vary appreciably with change of altitude, and estimated that in the worst case the range would not increase more than 2 per cent. between sea level and 15,000ft. It is of interest to note here that this same theory of Colonel Tizard's was brought forward again in 1929 to explain some of the results found from flight tests, and to suggest the procedure for further tests.

It is not possible to discuss here any of these papers in greater detail. They have been quoted, however, to show that for many years, while there was fairly general agreement that for maximum range at all heights flight should be made at a constant indicated air speed, considerable differences of opinion existed on the question of the variation of range with height.

It was unfortunate that for a long period very few practical measurements were available by which theory could be checked. A certain number of consumption tests on aircraft in flight were made at Martlesham Heath during the War and shortly after, and the general indication from these was that an appreciable increase of range with height occurred. The value of any such practical work, however, was largely vitiated by the unreliability of the only available instruments for measuring consumption, and also, incidentally, by a failure to appreciate the degree of accuracy of measurement required.

Between 1924 and 1927 very little work seems to have been done on the subject. The theoretical aspect was however re-opened in 1927 by Mr. H. L. Stevens, who in a report to the Aeronautical Research Committee[6] put forward a method of predicting the range of aircraft at various heights, using the measured performance of the aircraft and test bench figures for the engine. This method was based on full throttle flight tests, and led to the conclusion that the maximum range of an aircraft increased appreciably with height. This report led to the formation of the Range of Aircraft Panel later in the same year, and one of the principal recommendations of this Panel was for a series of careful flight tests. Fortunately the R.A.E. mass type flowmeter had at this time just made its appearance, and provided at last a quick and accurate method of measuring fuel consumptions in flight. It was therefore decided to start a series of direct tests at the A. and A.E.E., Martlesham Heath, in which the fuel consumptions of an aircraft in level flight at a series of heights should be measured.

Before describing the flight tests it has been thought desirable to point out some of the difficulties of measuring fuel consumption in the air, and to enumerate the theoretical arguments on the subject of the variation of range with height.

Measurement of Fuel Consumption in Flight

At first sight it would appear a simple matter to measure the fuel consumption of an aeroplane in the air, but it is very often quite a difficult procedure if

[5] Ref. 5.
[6] Unpublished.

accurate and consistent results are required. The difficulties in flying the aeroplane level at a definite value of the r.p.m. and at the same time adjusting the mixture to the required strength will be dealt with in a later section of the paper. Suffice to say at the moment, they are in themselves considerable. Apart from this, however, the actual measurement of the fuel consumed presents problems of its own.

An obvious method is to measure the time taken to use a given quantity of fuel, or, of course, the amount of fuel used in a given time. This fuel must either be contained in one of the tanks in the aircraft which can be isolated from the rest of the fuel system, or in some form of additional calibrated tank. The former case involves running one of the tanks of the aircraft dry in the air, with consequent risk of air locks in the system, or else entails measurement of fuel put into a tank at the beginning of a flight and drained out at its conclusion. In either case petrol may be lost through the vent pipes when taxying. Moreover, in most cases only one test can be made per flight. The method is therefore extremely laborious. The use of a special calibrated tank, unless it is to suffer from the same drawbacks, demands some arrangement whereby it may be filled from the main petrol system between tests. The installation necessary for this is by no means easy on all aircraft.

There are some fuel-measuring instruments based on the same principle, but they must all suffer from the disadvantage that the greater the accuracy required the greater must be the quantity of fuel measured, and therefore the greater the bulk of the instrument and the time taken to make any test. It will be seen, therefore, that except for aircraft with engines of very low consumption, the method is cumbrous and slow.

A much better way of measuring consumption is by means of a device to measure the fuel flow. Flowmeters of one sort or another have been known for many years, but it was not till the advent of the R.A.E. mass type flowmeter in 1927[7] that a really reliable and accurate instrument was produced. Most of the earlier instruments were of the type in which the *volume* of fuel passing was measured, and their readings were in consequence seriously affected by variations in temperature. At the low pressures obtaining at high altitudes liberation of the dissolved gas from the fuel also caused serious inaccuracies.

The R.A.E. Flowmeter

In the R.A.E. flowmeter both these difficulties have been overcome, first by measuring the mass instead of the volume of fuel passing, and secondly, by designing the instrument in such a way that the dissolved gases cannot accumulate inside. The instrument has the additional advantage that its readings are practically unaffected by changes in the viscosity of the fuel.

One of these instruments is shown in position on an aircraft in Fig. 2. Briefly, the flowmeter consists of a tapered brass tube in which is a sink with a sharp-edged top, the sink being kept central in the tube by a guide rod. The fuel flows through the annular space between the top of the sink and the tube, and owing to the taper of the tube the height of the sink in the tube depends on the mass of fuel passing. The height of the sink is observed by means of a tongue projecting from it which is visible through a cellon-covered slot in the side of the tube.

Instruments of this type have been in extensive use at experimental establishments for several years and have proved extremely accurate and reliable. Their only drawback is that, being gravity controlled, fluctuating readings are obtained if the atmospheric conditions are at all bumpy. Care must be taken

[7] Ref. 6.

always to instal them in the final supply pipe to the carburettor. A filter immediately before the flowmeter is essential, for the absence of this may cause erratic readings owing to the appearance of ice or foreign matter in the body of the instrument.

Testing of Flowmeters

Before use on aircraft on experimental work, flowmeters are invariably bench tested over their working range. The method used at the Marine Aircraft Experimental Establishment is fairly representative (Fig. 3). Petrol is delivered from a constant head tank via a control cock and the flowmeter, either to another tank from which it is pumped back to the constant head tank, or else on to a measuring vessel attached to a balance. The rate of flow is adjusted by means

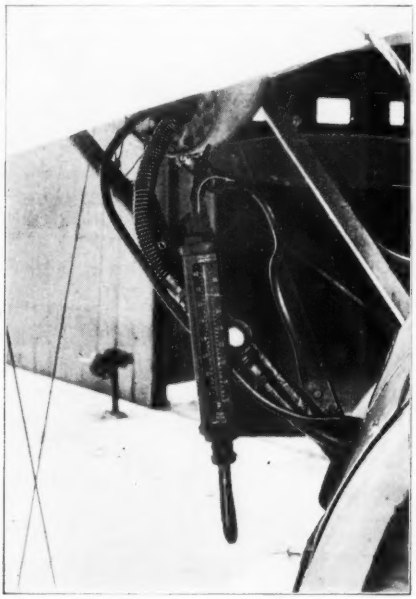


FIG. 2.

Flowmeter mounted on aircraft.

of the control cock. The action of diverting the flow to the measuring vessel starts a stop-watch, which re-diversion of the flow stops. The flowmeter is read at frequent intervals during a test and the mean indicated flow compared with that measured. Except for instruments damaged by careless handling it is rare to find errors in flowmeters exceeding one per cent.

Aerodynamics of Range

It is now proposed to deal briefly with the theoretical side of the question of range, with particular reference to the effect of height. The aerodynamics of the case are quite straightforward.

For an aeroplane in level flight at any height:—

If V be the true air speed in m.p.h.
H the b.h.p. of the engine at the r.p.m. corresponding to this speed.
D the resistance in lb. at this speed.
η the airscrew efficiency.
p the specific fuel consumption of the engine in lb./h.p./hr.

The range in miles per lb. of fuel

$$= V/pH = 550\, V\eta/1.467\, pDV = 375\, \eta/Dp.$$

For a given aircraft in level flight the angle of incidence is the same at the same indicated air speed at any height, assuming no change in weight. Hence the resistance is the same at the same indicated air speed. Also the advance

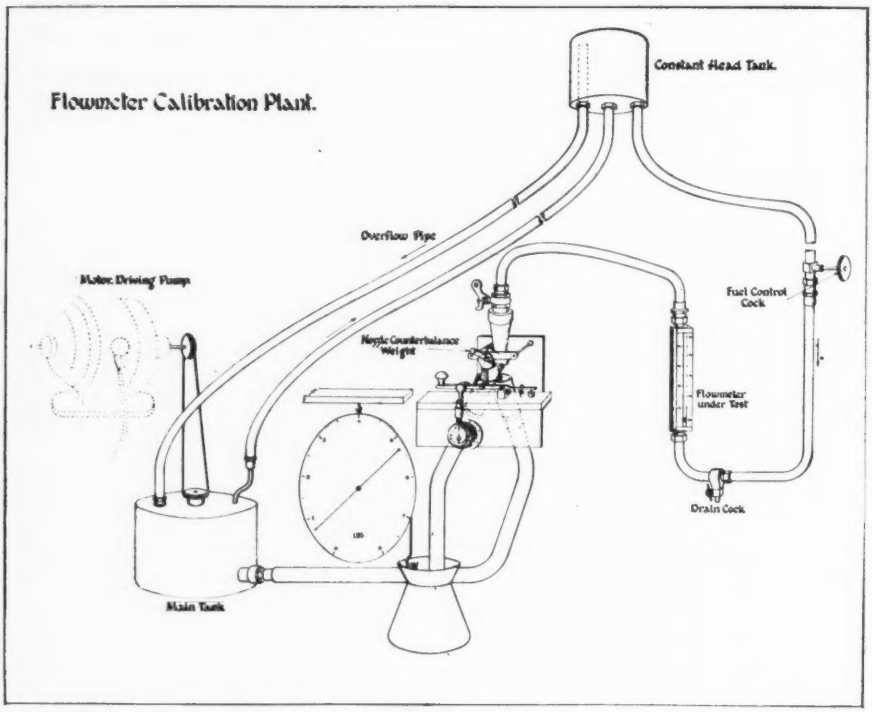


FIG. 3.
Flowmeter calibration plant.

per revolution of the airscrew, and hence the efficiency of the airscrew is the same at the same indicated air speed.

It therefore follows from the equation above that the range depends on the indicated air speed and the specific fuel consumption only. The range of an aircraft at any given indicated air speed is therefore inversely proportional to the specific fuel consumption of its engine.

For level flight at a given indicated air speed the torque of the engine is constant. The variation of range with height at any given indicated speed therefore depends on the variation of the specific fuel consumption at constant torque with height.

PART II.

Fuel Consumption of Engines

It has been shown by Col. H. T. Tizard[8] that, although there is no direct evidence on this point, the specific consumption is not likely to vary very much with height.

At the same indicated air speed the torque is constant, and therefore the mass of the charge entering the cylinders each stroke is nearly constant. At low heights the dilution by exhaust gases is greater, causing a lowering of the maximum temperature of explosion and a resultant increase of thermal efficiency, but this effect is probably slight.

The specific consumption depends, of course, on the mechanical efficiency. Now for constant torque, the greater throttling at low heights causes greater pumping losses, whereas the frictional losses are proportionately greater at high altitudes. Ricardo's tests on a number of engines have shown that these two effects approximately balance one another.

The above argument assumes the most economical use of fuel in the engine, and the best setting of the ignition timing at all times—two conditions which, as will be seen, are usually not found in practice.

The engine side of the range question therefore resolves itself chiefly into the problem of obtaining the greatest possible amount of work out of a given quantity of fuel, that is obtaining a low specific fuel consumption, which will be referred to throughout in terms of lb./b.h.p./hr. It is sometimes given in pints, but in this case the density, and therefore temperature, has to be considered, and

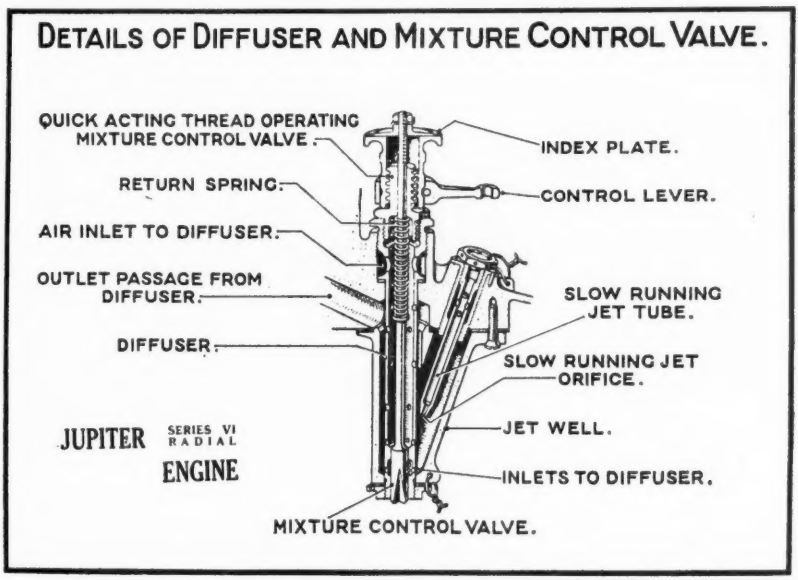


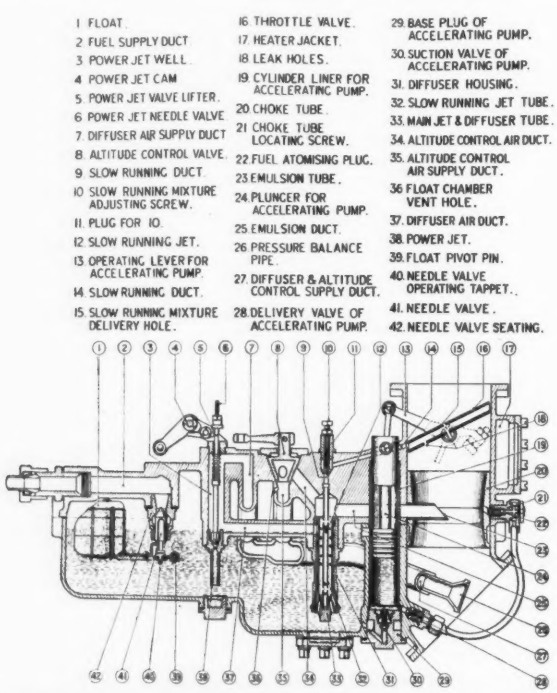
FIG. 4.

Mixture control valve, Bristol Triplex carburettor.

[8] Ref. 8.

the mass basis is more convenient for calculations. Unless otherwise stated the fuels considered are of the usual hydrocarbon type used in ordinary flying, for all of which the calorific value is very nearly the same.

It has long been recognised that the actual fuel consumption of an aeroplane will vary according to the nature of its work and the care with which it is handled, and this applies probably more to Service than to civil flying, where engine and air speed and height are usually much more uniform. Approximate measurements made some time ago in a R.A.F. bomber squadron showed, during a formation flight, variations between different aeroplanes of the order of 40 per cent. in the fuel consumption, and it is obvious that for consistently economical flying it is necessary first to find out what conditions are required to


1. FLOAT.
2. FUEL SUPPLY DUCT.
3. POWER JET WELL.
4. POWER JET CAM.
5. POWER JET VALVE LIFTER.
6. POWER JET NEEDLE VALVE.
7. DIFFUSER AIR SUPPLY DUCT.
8. ALTITUDE CONTROL VALVE.
9. SLOW RUNNING DUCT.
10. SLOW RUNNING MIXTURE ADJUSTING SCREW.
11. PLUG FOR 10.
12. SLOW RUNNING JET.
13. OPERATING LEVER FOR ACCELERATING PUMP.
14. SLOW RUNNING DUCT.
15. SLOW RUNNING MIXTURE DELIVERY HOLE.
16. THROTTLE VALVE.
17. HEATER JACKET.
18. LEAK HOLES.
19. CYLINDER LINER FOR ACCELERATING PUMP.
20. CHOKE TUBE.
21. CHOKE TUBE LOCATING SCREW.
22. FUEL ATOMISING PLUG.
23. EMULSION TUBE.
24. PLUNGER FOR ACCELERATING PUMP.
25. EMULSION DUCT.
26. PRESSURE BALANCE PIPE.
27. DIFFUSER & ALTITUDE CONTROL SUPPLY DUCT.
28. DELIVERY VALVE OF ACCELERATING PUMP.
29. BASE PLUG OF ACCELERATING PUMP.
30. SUCTION VALVE OF ACCELERATING PUMP.
31. DIFFUSER HOUSING.
32. SLOW RUNNING JET TUBE.
33. MAIN JET & DIFFUSER TUBE.
34. ALTITUDE CONTROL AIR DUCT.
35. ALTITUDE CONTROL AIR SUPPLY DUCT.
36. FLOAT CHAMBER VENT HOLE.
37. DIFFUSER AIR DUCT.
38. POWER JET.
39. FLOAT PIVOT PIN.
40. NEEDLE VALVE OPERATING TAPPET.
41. NEEDLE VALVE.
42. NEEDLE VALVE SEATING.

CLAUDEL HOBSON CARBURETTOR TYPE A.V.T.70.G.

FIG. 5.

secure low fuel consumption of the engine and then to ensure that these conditions are maintained.

Factors Affecting Fuel Consumption

Let us examine, briefly, some of the factors upon which the specific fuel consumption depends. There are, of course, very many of them, but the majority are influenced only by the design of the engine and we will confine ourselves now to those which can be varied either by the pilot in flight or by some simple adjustment on the ground.

The most obvious, and perhaps the most important, of these is the fuel mixture, that is the proportion of fuel and air supplied to the cylinder. (We say the cylinder advisedly, because it does not by any means follow that the same mixture that leaves the carburettor will arrive at the inlet port). For any fuel there is a fixed proportion of air which is necessary for complete combustion, normally known as the " chemically correct " mixture, but this is not found in practice to be that either for maximum power or for low specific consumption. The maximum power mixture is normally slightly richer than the " correct " mixture, *i.e.*, an excess of fuel is required. Further enrichment, however, causes a slight loss of power and at the same time an increase of fuel consumption, so such a mixture is thoroughly bad from an economy point of view, though it may be necessary for other reasons. Weakening the mixture, on the other hand, causes at first only a slight loss of power while considerably reducing the consumption ; in other words the consumption at first falls more rapidly than the power. The specific consumption, therefore, will be lower with a slightly weak mixture, but further weakening causes a more rapid falling off in power and the specific consumption begins to increase again.

Weak Mixtures and Distribution

For economy, therefore, we need a weak mixture, but the weakness is limited in practice by the ability of the engine to run smoothly on it. A weak mixture is not ignited so readily as a " correct " one, *i.e.*, a stronger spark is necessary, and when fired does not burn so rapidly and this applies to a greater degree at small throttle openings, when the dilution by residual exhaust gases is greater. Nevertheless, it would normally be possible to reach the most economical mixture without misfiring if only it were possible to provide this same mixture for all the cylinders of an engine. In modern aero engines having several cylinders, it is rarely, if ever, possible to approach this ideal condition. It is necessary, in order to ensure even running, that the weakest mixture supplied to any one cylinder shall be rich enough to fire regularly under the conditions obtaining, and consequently the mixture supplied by the carburettor to a group of cylinders must be richer than this to an extent which depends upon the equality of distribution. The distribution in turn depends on a number of factors such as the shape and size of the induction pipe, form of air intake, presence or absence of a blower and temperature of the induction system. Of these the only one at all under the control of the pilot is the temperature, in the case of water-cooled engines, and it is found that at great altitudes, where the temperatures are very low, this has an enormous effect on the richness of mixture required.

Engines differ very widely in this respect, and it is not always easy to account for their vagaries, but it is possible in an engine of reasonably good design to run on an average mixture some 10-12 per cent. weak with a power loss of 5-6 per cent., and considerable saving in fuel could then be obtained if it could be used all the time. Unfortunately, economical running is only one—and a secondary one at that—of the considerations in aero engine design. After reliability, which is of course essential, power development seems to be the first objective and for certain conditions, as for take-off and quick climbing, it is necessary to run the engine under maximum power conditions. Carburettors, too, are not perfectly automatic, and moreover quick acceleration cannot be obtained without somewhat enriching the normal mixture. This has, however, lately been improved by the introduction of the pump type of carburettor in which a small pump is attached to the throttle control and squirts a small quantity of petrol out of the jet when the throttle is quickly opened, without affecting the mixture for steady running. As a slightly rich mixture causes less loss of power than a correspondingly weak one, it is usual to set the carburettor somewhat on the rich side, to ensure that at the critical moment there will be no lack of power.

Altitude Control

All this points to the fact that when economy becomes, for the time, a vital consideration, it is up to the pilot to do what the carburettor cannot do for itself and provide the engine with a suitably weak and, therefore, economical mixture. Nearly all aeroplanes are provided with what is usually known as an "altitude control," which is simply a means of weakening the mixture normally supplied to the engine when required.

There are two main types of altitude control, one consisting of a variable jet in the carburettor, and the other depending on some form of pressure balance between the choke and float chamber. In each case the amount of weakening can be varied by a lever in the pilot's cockpit, and it is customary to fit stops so arranged that the altitude control lever cannot be opened beyond the throttle. It is worth noticing that the variable jet type of control is very much easier to operate smoothly and accurately than the pressure balance type, and is less affected by disturbances such as bumps, etc.

The altitude control was originally fitted to aeroplanes so that the pilot might correct the tendency to enrichment of the mixture as the aeroplane rises, and perhaps for this reason most pilots never make use of it for any other purpose, while even for altitude correction it is only used very sparingly and at a great height. Whether this is due simply to lack of thought, fear of loss of power, or a rather hazy idea that it might be bad for the engine, we cannot say, but the fact remains that by more generous use of the so-called altitude control, a fuel saving of the order of 10 per cent. can be obtained in steady flight without any dire results whatever.

For the utmost possible economy however, as for long range flights, the conditions must be controlled with greater precision than is practicable for ordinary every-day running, and in describing the experiments later on it will be indicated how this may be done.

Ignition Timing

Before going on to this, however, there is another variable which has to be considered, that is the ignition timing. For any particular engine the two main factors which determine the best timing are the engine speed and the throttle opening, greater advance being required for high speed and for small throttle opening. Although these controlling factors, while not being entirely inter-dependent, normally operate in opposite senses, it seems probable that for level flight the effect of throttling is more pronounced, and therefore more advance is required at the lower speeds. Now the most economical air speed for an aeroplane is always nearer the lower end of the speed range than the higher and the engine is running considerably throttled, except at or near the ceiling of the aeroplane, so that as far as economy is concerned it is important to have the ignition setting correct under these conditions. In the majority of engines at the present time the ignition is either fixed or inter-connected with the throttle in a more or less arbitrary manner, so that, while correct for full throttle running on the level, it is retarded as the throttle is closed. This is the reverse of what is required.

Flight Tests—First Series

It might be thought that all these things could be settled by bench and wind tunnel tests and a good deal of valuable data can certainly be obtained in this way, but it is exceedingly difficult to reproduce the conditions of flight on an engine test bench accurately, and once the line of investigation has been decided, the matter can only be definitely settled by recourse to actual flight trials.

The first serious attempt at this was made in 1928 at Martlesham Heath,[9] the aircraft used being a Vickers Venture, a two-seater general purposes aircraft with a Napier Lion Mk.Va water-cooled engine. For the fuel measurements two methods were used. The first consisted of a small supplementary petrol tank of about ½ gallon capacity, which was arranged so that by turning a tap it could be either filled from the main petrol supply or allowed to empty into the carburettor, the time of emptying being taken by the observer with a stop-watch. This method with due care gives quite good results, but whenever the fuel flow was enough to come within its range, use was made of the R.A.E. sink-type flowmeter, already described. With this instrument there are no taps to turn or time to take, and extensive tests have shown that the readings are practically independent of temperature or moderate vibration.

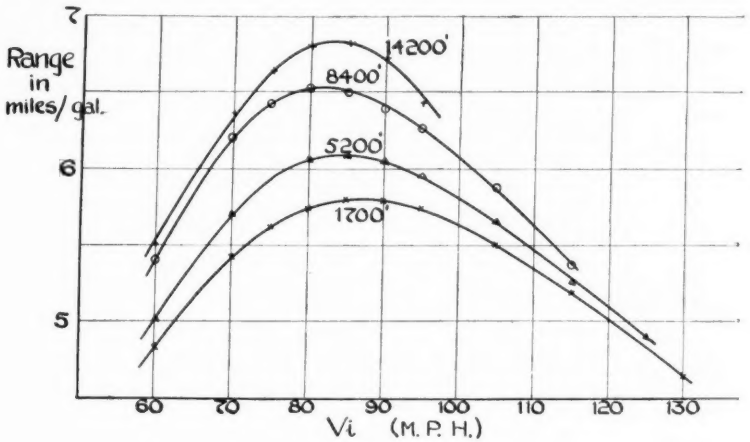


FIG. 6.

Variation of range with height.
Vickers Venture. Normal A.C.

In the Venture tests, consumptions were measured at four heights, viz., 1,700ft., 5,200ft., 8,400ft., and 14,200ft., and the mixture controlled by A.C. In one series the A.C. used was just enough to cause no fall of r.p.m., and in the other the r.p.m. were allowed to drop slightly and then brought back to their former value by opening the throttle. The first, here called "Normal A.C.," corresponds to the weakest full power mixture and the second to a slightly weaker but rather indefinite mixture. As the maximum power point is not very well marked, it was found difficult to get consistent results with Normal A.C.

These tests indicate that the range can be improved, especially at low altitudes, by weakening the mixture and that the range with both systems increased with height, the increase being more with Normal A.C. No attempt was made to use a very weak mixture as it was thought that it might cause damage to the engine.

The results did not altogether agree with theory, as pointed out by Col. Tizard[10], in that the range increased with height. Col. Tizard also suggested that if a weaker mixture were used, so as to get the best specific consumption at all heights, and also perhaps variable ignition, more satisfactory results might

[9] Ref. 8.
[10] Ref. 8.

be obtained, and he suggested as a weak mixture basis enough A.C. to drop the r.p.m. by 3 per cent.

Weak Mixture Effects

These suggestions led to the second series of tests which were made during 1930 on a D.H. Stag fitted with a Bristol Jupiter VI. engine. At the same time bench tests were undertaken at Farnborough to investigate fuel consumption with weak mixture and the effect of prolonged running at low consumption. These will be discussed first.

It is obvious that however advantageous it may be to fly on weak mixtures from the point of view of economy, this is of little practical value if the engine deteriorates internally so quickly as to necessitate frequent overhaul. Until recently it was widely thought that this would be so, even that failure might occur, though there was little direct evidence of this, and Ricardo does not consider that there should be any danger. The chief causes of possible trouble are :—

1. Excessive heating of the exhaust valves due to slow burning.
2. Scaling of the exhaust valves by the presence of excess of free oxygen.
3. Plug failure—cause not always clear.
4. In air-cooled engines, excessive heating of the cylinder heads through lack of free petrol.

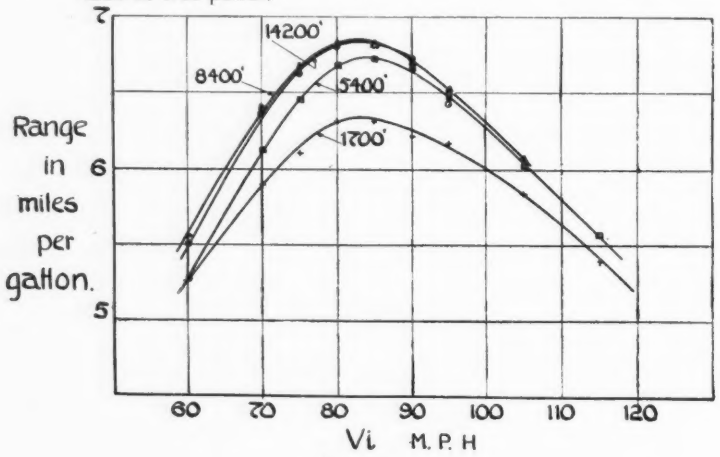


FIG. 7.

Variation of range with height.
Vickers Venture. Weaker mixture.

With regard to the last, it is probable that most, if not all, air-cooled engines when running at full power rely to some extent for the cooling of their cylinder heads and valves on the rapid evaporation of liquid petrol entering with the charge. For this reason, at full power, these temperatures are probably lower when an excess of petrol is provided. At low power, however, air-cooled engines seem to be able to run satisfactorily on weak mixtures and the temperatures of some parts, at any rate, seem to be lower.

Bench Tests

Tests were made at the Royal Aircraft Establishment during 1930 and 1931 on a Jupiter VIII engine,[11] to determine the effect on the engine of running on

[11] Reports unpublished.

weak mixtures and also of varying the ignition. The results are highly interesting, but for obvious reasons can only be summarised here.

The first test was for the purpose of finding the minimum fuel consumption. Consumption loops were taken at various speeds and throttle settings, and showed that the specific consumption can be reduced from the normal value of .6lb./h.p./hr. at full throttle to .5 with very little loss of torque. The minimum at high torque was about .43, but at this figure the running was usually unsteady, and it is, therefore, not practicable in flight.

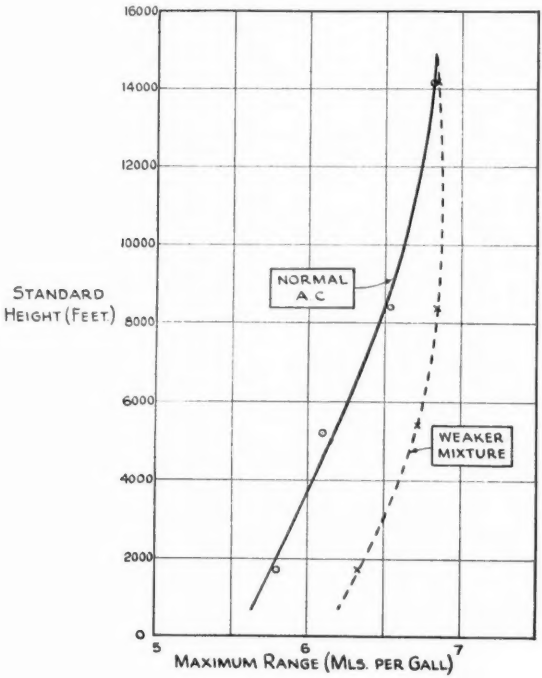


FIG. 8.

Variation of maximum range with height (Vickers Venture).

A 100 hours endurance test was then started with the weakest mixture possible for steady running at fairly high r.p.m. and torque. This gave .482lb./h.p./hr. Examination of the engine after the test showed the condition to be good, with the exception of exhaust valves which seemed to have been getting very hot. This might be expected on an air-cooled engine, where excess petrol helps considerably in cooling the valves under normal conditions. At the same time, it should be mentioned that this engine had an early type of cylinder head which is now replaced by one much better from the cooling point of view, which would probably give better results.

The effect of ignition setting was investigated by taking a number of consumption loops at values of throttle and r.p.m. corresponding to ordinary flight conditions. It has been shown that in level flight the ratio of torque to maximum

torque, for a given ratio of "indicated r.p.m." ($n\sqrt{\sigma}$) to maximum r.p.m., varies little between different aircraft, and, therefore, these tests are capable of general application.

The results showed that there was a definite advantage in over-advancing the ignition when using weak mixtures, especially at small throttle settings. Rough running, however, still sets a limit to the permissible weakening owing to unequal distribution. At very low B.M.E.P. and torque, trouble was found with oiled-up plugs, which might be avoided by using hotter running plugs and unbraided leads.

In addition to the R.A.E., some engine makers have conducted tests on weak mixtures, and a brief summary of the results follows:—

Messrs. Rolls-Royce did a 100-hour endurance test on a Kestrel engine in

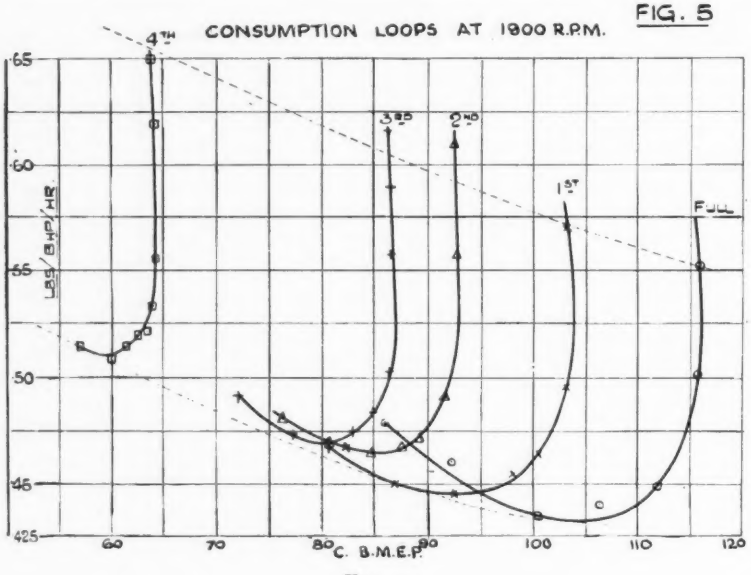


FIG. 9.

Consumption loops at 1,900 r.p.m.

1928. The distribution of these engines is good, and enabled a mixture 10-13 per cent. weak to be used with a power reduction of 5-7 per cent. At full throttle the consumption obtained was .48lb./b.h.p./hr., while throttled to about 300 b.h.p. the very low value of .43lb./b.h.p./hr. was obtained. When the engine was stripped there was absolutely no trace of damage due to weak mixtures. The only trouble experienced was due to oiling-up of plugs, and it was found impossible to run satisfactorily with braided H.T. leads, as these appreciably reduce the spark intensity. It was found that high water temperatures improved the consumption at low power, and advancing the ignition when throttled gave a definite increase of power.

The Bristol Aeroplane Company did a 50-hour test of a Jupiter VIII engine, running on consumption varying mainly between .50 and .55lb./b.h.p./hr. Temperatures were lower than with the chemically correct mixture, which also gives the worst detonation, although some oxidation of the exhaust valve seems

to occur. Again, advancing the ignition with weak mixture is definitely beneficial. Consumptions of the order of .43 have, we are informed, been obtained on the bench, but it is not considered likely by the makers that the engine would run continuously thus without damage.

Messrs. Armstrong-Siddeley have obtained specific consumptions on a Panther engine of .47-.48lb./h.p./hr. on the bench, but have done no extended weak-mixture tests, as they consider that, at any rate near full throttle, a consumption of less than about .56 is liable to cause damage. The best was obtained at about 55-65 per cent. of full power.

In connection with radial engines, it is worth noticing that, owing to the usual articulated con.-rod assembly, the actual ignition timing varies in the

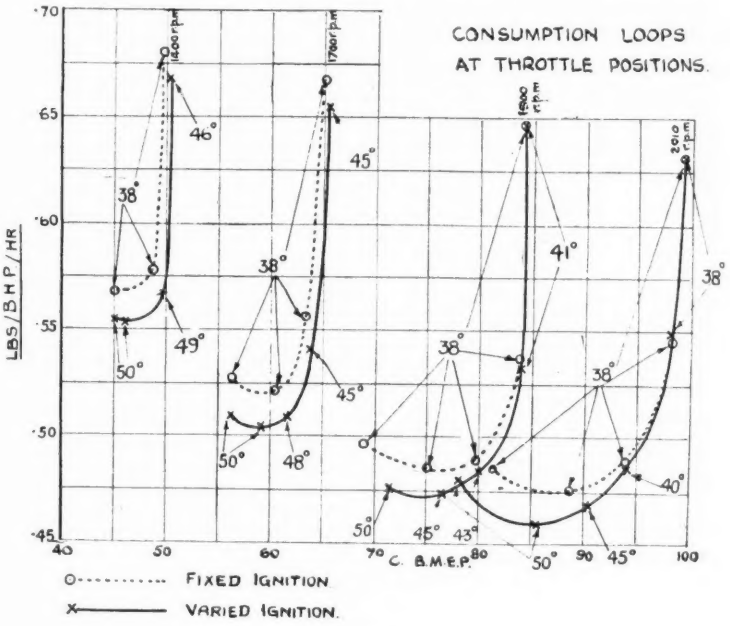


FIG. 10.

Consumption loops with variable ignition.

different cylinders by several degrees, and it is, therefore, impossible to have optimum conditions in more than two cylinders (four for a two-row engine) at once.

The Napier Company have also made experiments on weak mixtures, but, as most of their work has been in connection with the Fairey Long Range Monoplane, the results are of a confidential nature. In general they agree with those obtained by the other makers.

"Stag" Flight Tests

The second series of flight tests[12] was begun in June, 1930, at Martlesham Heath, the aeroplane allotted for the purpose being the De Havilland "Stag,"

[12] Ref. No. 9.

a machine closely resembling the well-known D.H. 9A, but with a Jupiter VI engine. The principal objects aimed at were :—

(1) To obtain consistent readings of consumption over a wide range of conditions, with, if possible, a greater degree of accuracy than had been previously obtained.

(2) To investigate the use of weaker mixture than had been used in the " Venture " tests.

(3) To investigate the effect of advanced ignition at small throttle openings.

It was decided to make flights at four heights, namely 1,500, 5,000, 10,000 and 15,000, and to cover the whole speed range of the aircraft at each height. To start with, the ignition was kept fixed at the then standard setting of 42°.

Three systems of mixture control were used, which are here referred to as " Service A.C.," " Normal A.C." and " Weak Mixture." In the Venture tests it had been found very difficult to get consistent results with weak mixtures, partly, perhaps, owing to the pressure balance type of altitude control, but in any case the system of using the A.C. was rather indefinite. It was hoped to avoid this with the Stag.

" Service A.C." corresponds to the ordinary method in common use, the altitude control being limited by stops, as previously mentioned.

" Normal A.C." represents the weakest full power mixture, and is obtained by opening the A.C. until the r.p.m. begin to drop and then closing it slowly until they just regain the former value.

" Weak Mixture " involves a definite drop in r.p.m. of 3 per cent. In a few observations it was found that unsteady running occurred, and the mixture was not weakened quite so much. The fuel flow was measured when possible by a flowmeter, but at first one was not available with a sufficiently low reading and an auxiliary calibrated tank was used. A Statoscope or a low-reading altimeter was used to assist level flight. The procedure was as follows:—

The Stag, being a two-seater, an observer was carried who concentrated on taking readings of flow. The pilot, having climbed to the required height, flew level at or about the desired air speed, and, when steady conditions were obtained, noted the r.p.m. and the A.S.I. reading. Simultaneously, the observer read the flowmeter and also checked the air speed from his own A.S.I. The flowmeter reading often fluctuated considerably, and steady flight conditions were maintained for a period before taking any readings, and then for two or three minutes, so that a mean of several readings could be taken. It is, of course, essential that the air be calm enough to enable the speed to be kept steady, to, say, $\pm$ 1 m.p.h., as every bump affects the speed, which, in turn, causes a momentary change in r.p.m., this temporarily disturbing the steady state of the induction system of the engine, which is not restored for some seconds after the original air disturbance has passed. This effect is particularly noticeable when running on weak mixtures, as the engine is then very near the unstable condition, and any slight disturbance has a much more marked effect.

For " Service A.C." tests it was usually sufficient to open the A.C. up to the stop, and no particular care was required. Moreover, with the mixture slightly rich, the engine is not nearly so sensitive to small changes, and consequently these tests were much easier and quicker.

With " Normal A.C." a certain amount of care is required. Having got the machine in steady level flight, the pilot opened the A.C. very slowly, keeping the machine level all the time, until a slight fall in r.p.m. occurred. The A.C. was then closed slightly until the former steady r.p.m. was regained. The readings were then taken as before.

It is the " Weak Mixture " tests, however, which are in themselves most interesting. In this case the pilot started as before by flying level at a suitable

speed, until steady conditions were obtained, during which time the r.p.m. were carefully noted. Then the A.C. was opened slowly until the r.p.m. dropped 3 per cent., the air speed of course falling at the same time. In this case it is particularly important to keep the aeroplane level all the time, as the engine is in an extremely sensitive condition, and it is also necessary to ensure that any variation in r.p.m. is really the effect of A.C., and not of some temporary disturbance. This was checked, after the readings had been taken, by closing the A.C., when the r.p.m. should rise by the same 3 per cent., and any observation in which this did not occur was treated with suspicion. Except in the calmest weather, it often takes about five minutes to get the conditions steady.

All this, coupled with the effect of cold and rarefied air at high altitudes, demands considerable concentration on the part of the pilot if consistent and accurate results are to be obtained, and it is not to be expected that consumption in ordinary flying could be improved to the extent which is possible under research conditions. At the same time, it is probably safe to say that considerable economy could be effected, without any great effort, if only the pilot realised that the "altitude" control has other uses than mere correction for great altitude.

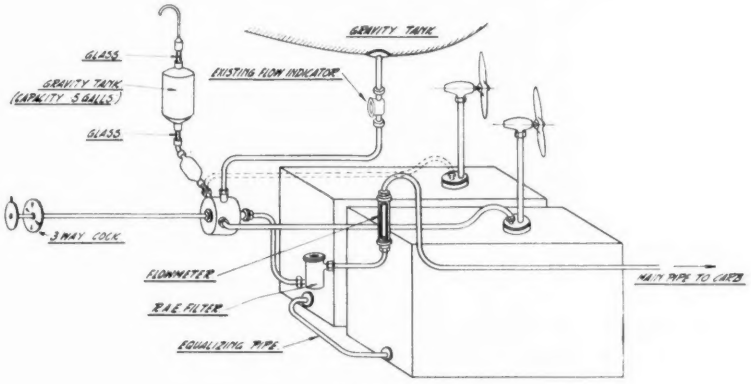


FIG. 11.

Petrol system for D.H. Stag tests.

The method of observation with the auxiliary calibrated petrol tank was, of course, slightly different. The tank was fitted on the rear port centre-section strut and connected in the petrol system in such a way that by the use of the main petrol cock only, it could be filled from the gravity tank of the aeroplane or allowed to empty into the engine, or the petrol could be supplied in the normal way.

To do a test the tank was filled, and when the desired condition of steady flight was attained the tap was turned so as to empty the tank, the main petrol supply being cut off. The observer noted the time taken for the tank to empty, and, as soon as it was empty, the pilot immediately switched over to normal petrol supply in order to prevent the engine stopping. The tank held approximately half a gallon, and took about three minutes to empty.

When a fairly comprehensive set of figures had been obtained, it was decided to investigate the effect of a change in ignition timing. The previous work had all been done with the then standard advance of 42°, but when this was altered to the present figure of 35°, a preliminary test was made at 5,000 ft. with weak mixture. The result indicated that the retarding of the ignition had an adverse

effect on the range at low speeds, and so on the maximum range, but little, if any, on the high speed figures. It was then decided to arrange for the ignition to be controlled from the cockpit, and when this was done further tests were made. In order to eliminate any possible effect of the variation in spark intensity at different positions of magneto advance, all the tests were done with the magneto cam ring set at full advance, the firing point being altered by adjusting the vernier magneto coupling, while the pilot's control was only used to retard the spark for taking off and full throttle running when the full advance was greater than normal. Unfortunately, before these tests could be completed the aeroplane became unserviceable; so that up to the present the effect of ignition advance has not been thoroughly investigated. Such work as has been done, however, shows that, at any rate at small throttle openings, advancing the ignition gives improved results. Further tests are now in progress.

Part III.

Results of Tests on Stag

Some representative consumption curves obtained at a height of 5,000 ft. with all three methods of adjusting the mixture strength are shown in Fig. 12.

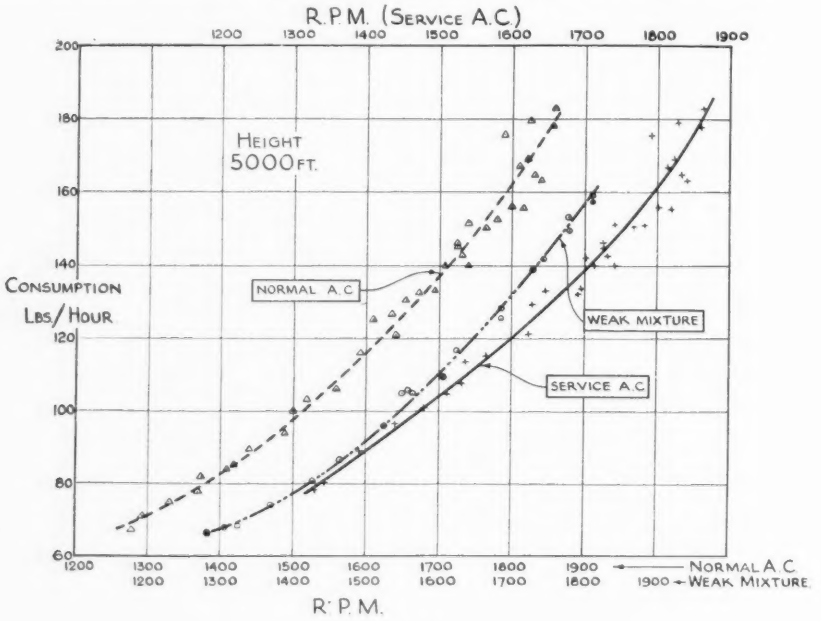


Fig. 12.

Representative consumption curves.
D.H. Stag (Jupiter VI).

The actual experimental points have been shown on these curves. Similar curves were obtained at each of the other three heights at which the tests were made. The scattering of the points at the high speed end of two of the curves illustrated is rather more than would normally be obtained, owing to an uncertainty in the r.p.m. on some of the tests due to the fluctuations of a faulty indicator. For-

tunately this occurred at those portions of the curves which are of the least interest from the point of view of range.

Curves in which the r.p.m. are plotted against the indicated air speeds for all the tests are shown in Fig. 13, and illustrate the number of observations taken

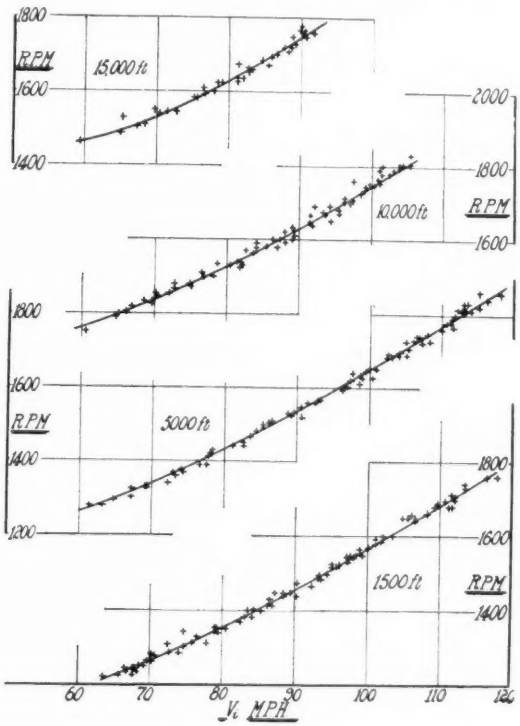


FIG. 13.

D.H. Stag.

R.P.M. and indicated air speeds at four heights.

and the degree of accuracy with which level flight was attained. These curves have been corrected for changes in the weight of the aircraft during the tests.

The ranges[13] of the aircraft at all speeds and heights for each method of adjusting the mixture strength, obtained from the smooth curves similar to the preceding figures, are shown in Fig. 14. This figure illustrates fairly conclusively

[13] NOTE.—It is of course realised that the figures given for range are of more academic than practical interest, in that the actual ranges are affected by the change in the weight of the aircraft due to consumption of fuel. The problem under discussion, however, concerns *relative* ranges for a given aircraft under various conditions, and for this purpose it is simpler to consider the range as being given directly by dividing the speed by the consumption. If required, true ranges may be obtained to a close degree of approximation by multiplying these by $\frac{2W_1}{W_1 + W_2}$, where W_1 is the initial loaded weight of the aircraft and W_2 is the weight when all the fuel has been consumed.

the effect of the various methods of using altitude control. It will be seen that at all speeds and at each height the ranges are highest under " Weak Mixture " conditions, that is with the application of sufficient altitude control to cause a drop in the r.p.m. of 3 per cent. The lowest ranges throughout are obtained with " Service A.C.," that is to say with the stops limiting the movement of the altitude control lever in place. Since the object of making these latter tests was

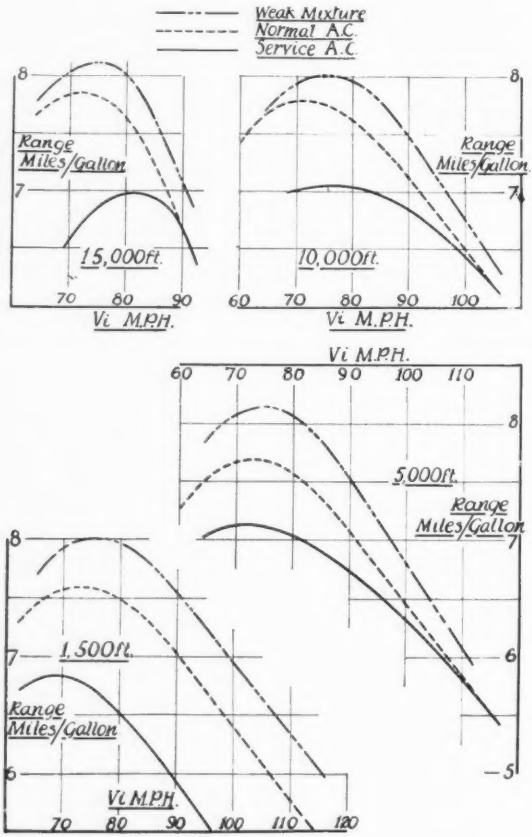


FIG. 14.

D.H. Stag.

Effect of altitude control on range at four heights.

to compare the ranges under Service conditions with those attainable with other methods of controlling the mixture strength, no altitude control was applied for the " Service A.C." tests at 1,500 ft., as it was considered that a Service pilot would not normally use the control at this height. At the other heights the maximum amount of altitude control permitted by the stops was used under throttled conditions, and the maximum amount possible without a fall in the r.p.m. when near full throttle. The ranges with " Service A.C." at 1,500 ft.,

therefore, are lower than would have been obtained if altitude control had been used.

The range curves have been re-plotted in the next figures (Figs. 15, 16, and 17) to show the variation of range with height for each method of using altitude

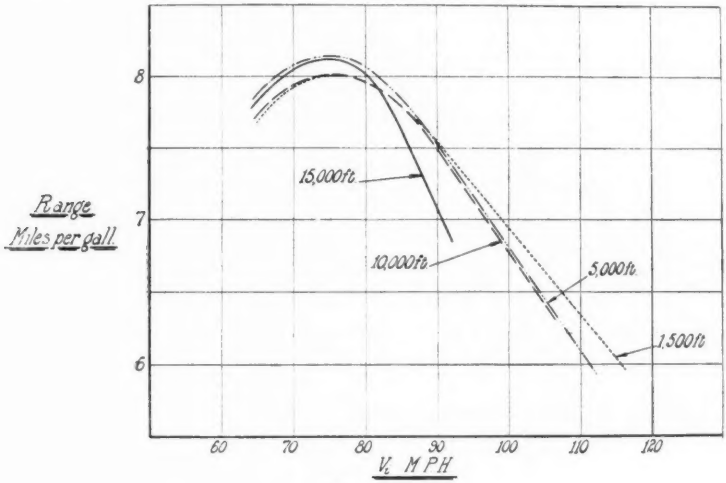


FIG. 15.

Variation of range with height.
D.H. Stag. "Weak mixture."

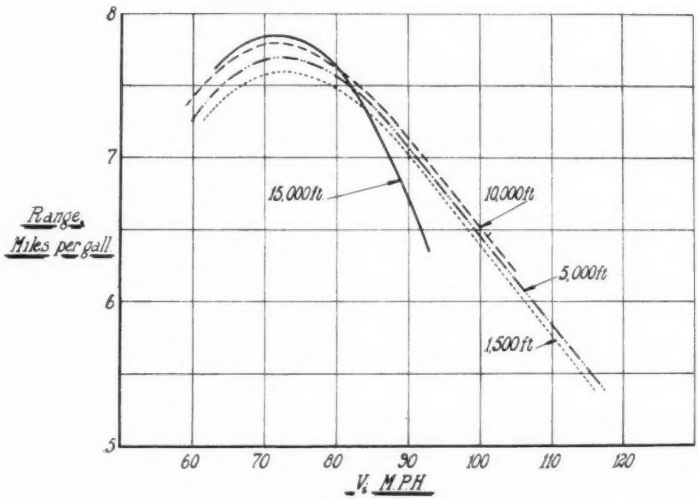


FIG. 16.

Variation of range with height.
D.H. Stag. "Normal A.C."

control. An interesting point brought out by these curves, which has so far eluded explanation, is the rapid falling off of range after the maximum for each of the curves at 15,000 ft. This occurs for each method of using altitude control, and hence appears to be independent of the mixture strength.

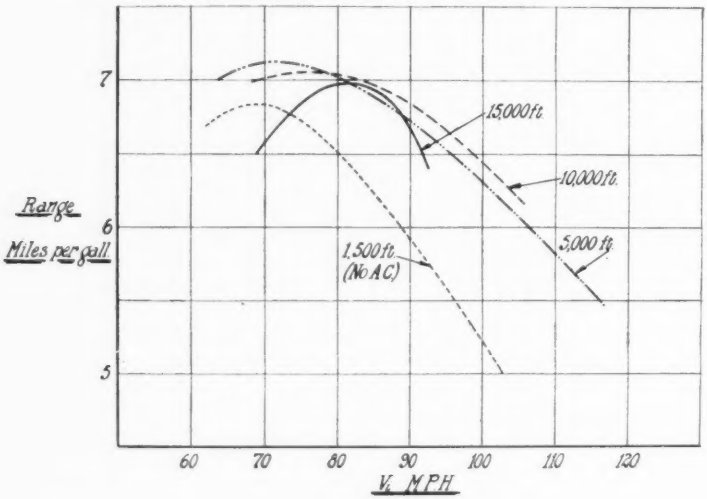


FIG. 17.

Variation of range with height.
D.H. Stag. "Service A.C."

The values of the maxima of the range curves are plotted in Fig. 18, so that this figure shows the variation of the maximum range with height for each method of controlling the mixture strength. It will be seen that under "Weak Mixture" conditions the maximum range appears to remain constant with height. The value of the maximum range at any of the heights at which tests were made is within 1 per cent. of the mean maximum range of 8.07 miles per gallon. With "Normal A.C." an increase in range of about 4 per cent. occurs between the ground and 15,000 ft., as compared with over 20 per cent. for the Vickers Venture. With "Service A.C." the maximum range decreases slightly with height above 5,000 ft., while below this height there is a sharp fall owing to the altitude control not having been used.

The most economical speeds at each height are shown in Fig. 19. For "Weak Mixture" practically no change with height occurs. Thus it will be seen that with this strength of mixture the maximum range appears to occur at a constant indicated air speed and to remain constant with height. In this it agrees with the theory put forward by Col. Tizard for the conditions of maximum economy. The ignition setting was, however, fixed. With "Normal A.C." a slight fall of V_i with height occurs, and with "Service A.C." a rapid increase. The shape of this latter curve is of course largely determined by the position of the stops, and has no theoretical significance.

Effect of a Change in Ignition Advance

As already mentioned, very little work has been done as far as flight tests are concerned on the effect of altering the ignition advance, so that the results

so far obtained are put forward very tentatively. The flight tests on which any reliance can be placed are consistent in themselves, however, and agree with test bench experience. It has therefore been considered worth while to quote them. It is emphasised, however, that it would be wise to refrain from drawing general conclusions on the effect of ignition advance until the results of further flight tests which have just been started are available.

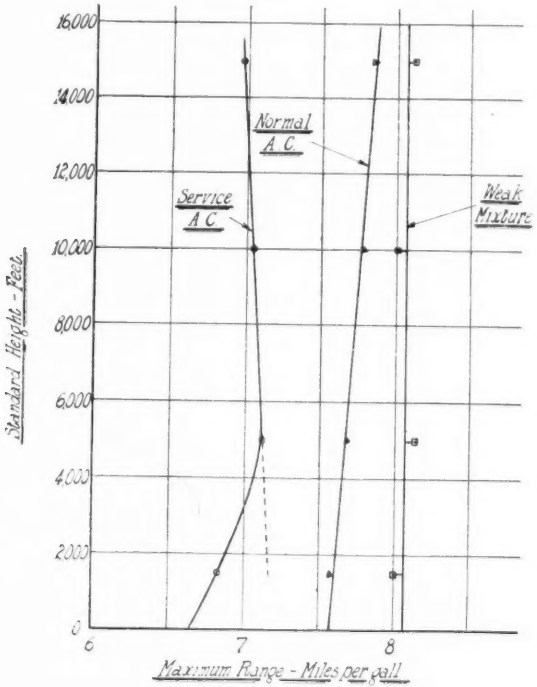


FIG. 18.

Variation of maximum range with height.
D.H. Stag.

The results of the tests on the Stag with weak mixtures at 5,000 ft. when the ignition advance had been changed from 42° to 35° are shown in Fig. 20 in the form of a curve of consumption against r.p.m. The dashed line in this figure is a reproduction of that previously obtained with an ignition advance of 42°, and the points and the full line through them represent the results obtained with 35° advance. It will be seen that over a large part of the range similar results were obtained with either advance, but that at the smaller throttle openings rather higher consumptions occurred with the more retarded ignition. The corresponding range curves are shown in Fig. 21, and, although the shape of the curve with 35° advance is of doubtful accuracy owing to the few observations taken, it serves to give an indication of the effect of a change of 7° in the ignition advance on the range of this aircraft at the speeds corresponding to small throttle openings. These results, in conjunction with the bench tests previously mentioned, show that when seeking economy the question of ignition advance is well worth

following up. Further flight tests, however, are required before any general conclusion may safely be drawn, and the results of those at present in hand will be awaited with interest.

Conclusions from Direct Tests

As comprehensive tests have, so far, only been made with two types of aircraft, generalisation on a basis of the results obtained would be unwise. It was found, however, that these results are in very good agreement with both the theoretical side as put forward by Col. Tizard and with bench tests, and, in view of this, it is reasonable to regard them as being capable of some general application. Unfortunately no similar tests have, so far, been made with aircraft fitted with supercharged engines, but it is hoped that it will be possible to make some in the near future.

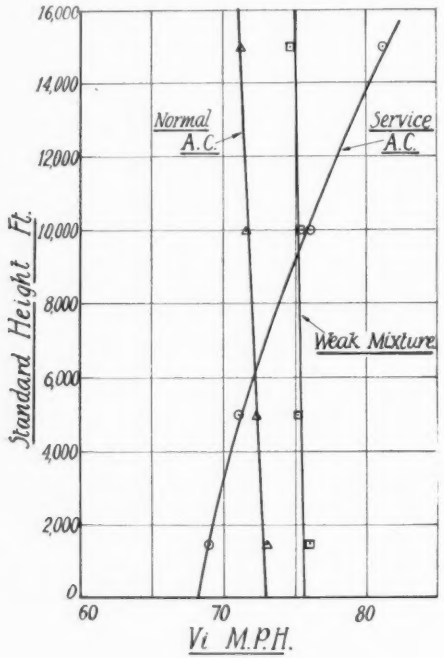


FIG. 19.

Most economical speeds at heights.
D.H. Stag.

We should like to have been able to quote figures obtained with other aircraft, and the results of a large number of consumption tests on different types of aircraft have been examined in the hope of extracting from them information relevant to this paper. Few records have been found, however, of tests on which complete observations had been taken, and in the majority of those examined the accuracy of measurement has been low. It was therefore decided to refer only to those tests of which the authors had had personal experience. No records of any other flight tests using weak mixtures have been discovered, and additional information on this subject would be valuable. It is emphasised, however, that

the utmost care is necessary in making the tests and that a large number of observations are required. The subject is essentially one on which tests of a rough and ready nature are liable to give most misleading results.

The results of the Martlesham Heath tests on the Stag indicate an appreciable reduction in consumption and a corresponding increase in range at all heights if the mixture is weakened sufficiently to cause a drop in the r.p.m. of 3 per cent. When this is done the maximum range occurs at a constant indicated air speed, and does not seem to vary with height. There are indications that further economies in fuel consumption might be effected by advancing the ignition

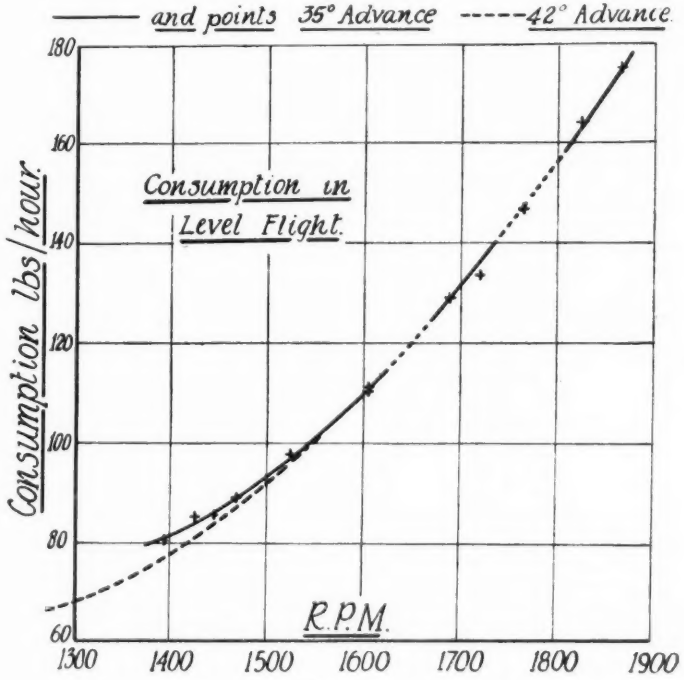


FIG. 20.

Effect of a change in ignition setting on consumption at 5,000ft. D.H. Stag.

when the engine is throttled. It is not considered that any further weakening of the mixture would have been practicable on these tests, as with a 3 per cent. drop in the r.p.m. the running of the engine was on occasion irregular, but it is suggested that in future tests attempts should be made to obtain consumption loops at various throttle settings in order to establish more definitely the best mixture strength.

For both the Stag and the Venture the maximum ranges under "Weak Mixture" conditions were approximately 5 per cent. greater throughout than those with "Normal A.C." For the Stag they were as much as 15 per cent. greater for "Weak Mixture" than for "Service A.C."

It is not suggested that mixtures as weak as this can be used at the present time in ordinary routine flying on all types of aircraft, for the precision of

adjustment of the altitude control necessary on many aircraft is greater than may reasonably be expected from pilots. With the advent of automatic A.C., however, this difficulty would, of course, disappear, and the use of weak mixtures might become more general.

Apart from weak mixtures, the effect of removing the stops limiting the movement of the A.C. lever and using the control with reasonable care, in other words, the effect of changing from " Service A.C." to " Normal A.C." is to cause an average increase in maximum range of over 10 per cent. in the case of the Stag. There is no doubt that very similar results would be obtained on many other aircraft.

With " Normal A.C." for both the Stag and the Venture the maximum

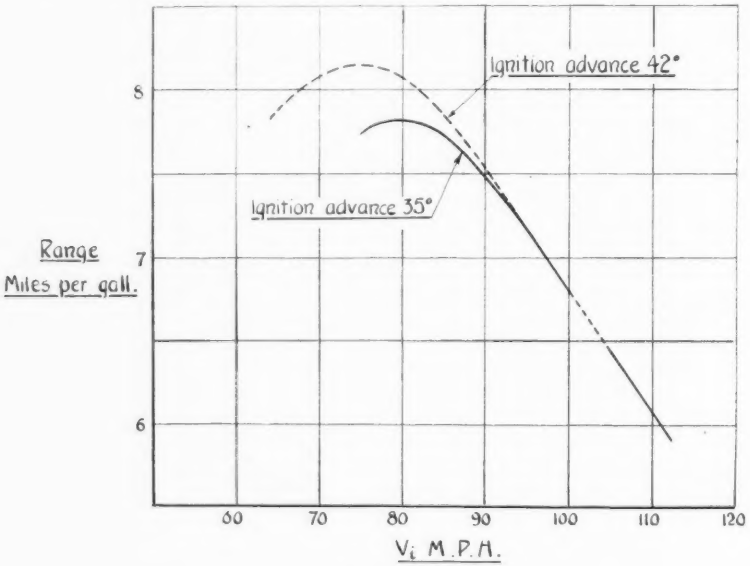


FIG. 21.

Effect of a change in ignition timing on range at 5,000ft.

D.H. Stag.

range increases with height, the increase for the Stag being very much less than for the Venture.

Points Arising from the Tests

One of the most important results of the work on range and fuel consumption is the very definite confirmation of the more or less vaguely realised fact that we are at the present time running engines in aircraft under conditions far removed from the most economical, especially at relatively high altitudes. There are many reasons for this, and consequently many ways in which an improvement is possible. There is no doubt, however, that considerable economies would ensue if the engines in aircraft were run on mixtures appreciably weaker than those at present in general use. It seems also that, with proper precautions taken, no ill effects on engines would result if this were done.

Limitation of Altitude Control by Stops

One of the principal causes of waste of fuel is the fitting of a stop to the throttle lever, or interlinkage between the levers, so arranged that the amount of " altitude control " that can be given is limited by the position of the throttle lever. Even if limitation of the amount of altitude control is desirable—a question which is in itself controversial—it is certainly not always desirable to limit it in this particular manner, for many carburettors to-day are so designed as to require approximately the same amount of A.C. at all throttle openings to give a constant strength of mixture. Moreover, in the future this feature is likely to be more general. Be this as it may, on many present-day aircraft it is not possible to give enough altitude control to cause a drop in the r.p.m. at all throttle openings, with the stops in place. The engines of these aircraft therefore will be habitually supplied with too rich mixtures at the lower throttle openings, in fact at the very part of the speed range where economy is desirable.

The fault must in general be laid at the door of the aircraft manufacturer rather than that of the engine maker. The latter usually fits a stop on the engine to limit the movement of the quadrant operating the altitude control, and the aircraft manufacturer has to provide an additional stop at the operating lever in the cockpit to come into action first and so prevent damage to the quadrant or control rods by clumsy manipulation of the control by the pilot. The position of the second stop, or interlinkage between the A.C. and throttle levers appears frequently to be chosen more or less arbitrarily. In fact the authors heard of a case recently in which a well-known type of aircraft which has been fitted with at least five different types of engines, was found to have a standard interlinkage between the throttle and A.C. levers irrespective of the type of engine fitted. Needless to say, with some engines the aircraft was found to be highly extravagant with fuel. This case illustrates the need for rather closer co-operation between the aircraft and engine makers if the fitting of stops is to continue.

The authors however suggest that there is quite a strong case for the abolition of any positive means of limiting the amount of altitude control. Such abolition would certainly tend towards economy, as it would enable the correct mixture strength to be used over the whole of the range of throttle openings instead of over only part of it, as is often the case at present. It is probable, too, that it would encourage pilots to make more use of their altitude controls, for in many aircraft at the present time the A.C. has no apparent effect over part of the range of throttle openings, and in general a pilot is more likely to make use of a control when he can see that his action is having some effect.

Opposition to the suggestion is likely to be based on the same reasons for which the stops were originally fitted, *i.e.*, fear of damage to the engine by the use of excessively weak mixtures. This question has been discussed in an earlier part of the paper, and is admittedly controversial. The weight of evidence, however, tends to show that the supposedly harmful effects of weak mixtures are generally considerably exaggerated, and that existing engines can be run continuously on mixtures appreciably weaker than those commonly in use with no ill effects whatever.

Even if engines can be damaged by the use of weak mixtures, this is no argument for the retention of the present system, for the stops do not prevent the use of exceedingly weak mixtures at large throttle openings at low altitudes, unless the carburettor is tuned excessively rich. If, therefore, damage to the engine is possible it is almost as easily caused with the stops in position as without. When flying an aircraft fitted with a supercharged engine below the supercharged height, a pilot can cause serious damage to the engine by flying with the throttle too far open. He is not, however, prevented from doing so by the fitting of stops to the throttle lever, but has to be guided by the reading of

a boost gauge. It seems equally logical therefore for a pilot to be guided in applying altitude control by the reading of an r.p.m. indicator, especially when there is much more doubt as to whether damage will ensue as a result of misuse of the control.

General Use of " Altitude Control "

At the present time the greatest amount of altitude control generally applied, when the stops or interlinkage permit, is what we have called " Normal A.C.," *i.e* , the maximum amount which can be used without causing a fall in the r.p.m. We consider that this amount might well be increased so that it became the current practice to use sufficient altitude control under cruising conditions to cause a definite drop in the r.p.m. For modern water-cooled engines, at any rate, this drop may be of the order of 3 per cent. In this connection it is interesting to note that until recently it was not permissible for pilots of the Royal Air Force to use more than " Normal A.C." under any circumstances, but that since August, 1931, they have been allowed to use sufficient altitude control to cause a drop of 20 r.p.m. when the throttle is less than three quarters open. They are also encouraged to regard the so-called " altitude control " more as a mixture control and to use it independently of height. This should lead to appreciable economies.

The very name " altitude control " has been responsible for a disinclination to operate the control at low altitudes, and the authors consider that this designation should be abolished altogether and some term such as " mixture control," " economiser " or " compensator " adopted in its place. A year or two ago a certain commercial air line obtained immediate and considerable economies in fuel consumption on one type of aircraft at low altitudes by merely changing the name " altitude control " to " compensator " and drawing their pilots' attention to its existence. By way of contrast may be quoted the case of an existing air line on which, we are informed, the carburettors are adjusted to give what bench tests indicate will be economical consumptions under cruising conditions in the air, and the altitude controls are then locked. There is something to be said for this practice in the case of an air line where most of the flying is done cruising at low altitudes, but it suffers from the disadvantages of any rigid system of limitation, that in order to prevent an excessively weak mixture being supplied under any conditions of running the mixture normally supplied must be stronger than the most economical. Moreover, it removes any inducement to the pilots to economise in fuel.

The difficulties met in obtaining a definite mixture strength in the air have already been mentioned, the chief one being that the curve of specific consumption against power is rather flat at the minimum with which we are concerned. In addition there is the difficulty that the only indication to the pilot of the power being developed by the engine is that given by the r.p.m. indicator. This is always a very insensitive measure, for in level flight the power depends on the cube or some higher power of the r.p.m. The mechanical type of r.p.m. indicator in general use, with its long flexible drive, gives at the best of times an indication which is not particularly steady, and which more often than not cannot be read with certainty to within 20 r.p.m. The electrical type of r.p.m. indicator which has been coming into use more generally of late, gives a much steadier reading owing to the elimination of the long mechanical drive. The development of a reliable type of electrical indicator with an open scale should itself cause economies in fuel consumption.

Another small point is that accurate adjustment of the altitude control lever is often difficult on present day aircraft owing to the small size of the lever, with high gearing and consequent stiffness of operation. A larger lever with a greater

movement, preferably mounted independently of the throttle, would make the task of the pilot very much easier.

Future Developments—Carburettors

We have shown that the present time aircraft are normally flown uneconomically, and we have also endeavoured to show some of the directions in which an improvement may be sought with the use of aircraft and engines as they exist to-day. It now remains to discuss the lines along which development is likely to proceed in the future in order to attain more economical conditions generally, and especially at high altitudes.

One of the most important requirements is an improvement in the design of carburettors. As already mentioned, the general tendency has been to design the carburettors for aircraft engines primarily for power and acceleration. Economy has been very much a secondary consideration, and even then has usually only been acquired at or near full throttle at the expense of extravagance at lower throttle openings. We do not wish in any way to minimise the importance of power or acceleration, but it seems to us that to maintain that an improvement in economy can only be obtained by sacrificing power and acceleration is an admission of failure. Economy at full throttle is of relatively small importance, since the amount of flying done at full throttle is a very small proportion of the total for normal aircraft. It is at the smaller throttle openings rather that economy is required. A promising line of development to this end appears to be that of the carburettor with a main jet system designed primarily for economy and an additional or " power " jet which only comes into use at or near full throttle, good accelerative powers being attained by means of a pump, as previously described. Certain types of carburettor embodying this principle are already in general use, and it is considered that it will be still further developed in the direction of economy in the future.

Automatic Altitude Control

When discussing weak mixtures the difficulty of adjusting the altitude control in an aircraft to give a definite mixture strength was mentioned, and a comment made to the effect that the delicacy of adjustment was often such as to be unsuitable for use in routine flying. This, combined with the ever-present need for giving the pilot fewer controls to operate and instruments to watch, makes the development of some entirely automatic form of mixture compensation very desirable. This development has been mentioned subsequent to emphasising the necessity for an improvement in carburettors, not because it is considered of secondary importance, but because it is essentially a *mixture* control, and it is the carburettor proper which provides the mixture which is to be controlled or compensated for a change in the external conditions. Unless therefore we have a perfect mixture in the first place, the automatic altitude control will merely perpetuate its imperfections. Hence we must first have good carburation to provide a suitable mixture, and then maintain the suitability of this mixture under changing conditions by means of an automatic altitude control.

A certain amount of theoretical and experimental work has been done and considerable progress made towards the development of a satisfactory device of this nature. The line of attack has generally been that of a diaphragm deflected by changes in the atmospheric pressure, and operating a mixture control valve through a relay mechanism of some description. The problem, however, is by no means simple, and it is quite possible that the automatic altitude control of the future will be operated in an entirely different manner.

Improvement of Distribution

The third direction in which improvement may be made in order to secure greater economy is that of distributing the mixtures to the cylinders of the engine.

Improvement in one direction is of limited use without some corresponding improvement in another, for the problems of carburation, compensation and distribution are, of course, to a large extent interlinked. It is of little use having an induction system of theoretically perfect design—if there is such a thing—if owing to bad carburation or compensation the mixture to be distributed resembles rain rather than mist; although, of course, an improvement may be made. Similarly the mixture may be excellent when it leaves the carburettor but very different when it reaches the cylinders, or even some of the cylinders; though here again a good mixture is easier to distribute than is a bad one.

When seeking economy, distribution is of paramount importance, for one of the essentials for true economy is that every cylinder of the engine shall be supplied with an equally weak mixture. When running on weak mixtures both on the flight tests on the D.H. Stag, and on the bench tests at the R.A.E., the degree of weakening attainable was limited by the uneven running of the engine, due to the fact that some of the cylinders were receiving excessively weak mixtures while others were still being supplied with a mixture giving satisfactory combustion; in other words, it was limited by bad distribution. This, incidentally, was with a radial engine with which good distribution might be expected to be relatively easier to attain.

By way of contrast may be mentioned a 12-cylinder Vee engine fitted with four carburettors which was demonstrated to the authors recently. When running on the bench the mixture was weakened until a fall in the r.p.m. of no less than 20 per cent. occurred and the colour of the flames at the exhaust was green, and yet no unevenness of running was apparent, pointing to excellent distribution. Another firm claim "perfect distribution" for a 14-cylinder radial engine with two carburettors. Yet another firm produce a 12-cylinder Vee engine with six carburettors which, if the makers' figures are to be believed, gives lower specific consumptions than any of the above engines, and what is even more important a much smaller fall off of specific consumption with throttling. To quote a concrete figure, for a certain engine of this type with a normal compression ratio, the specific fuel consumption appears to be below 0.5 lb./h.p./hour when throttled to half power. This seems to indicate that a profitable line for development may be the provision of more carburettors. On the other hand this practice is regarded with distinct aversion by many engine designers.

It is likely that in the future superchargers will be used to a greater and greater extent. It was thought at one time that superchargers would be the solution of all difficulties in carburation and distribution, owing to the effect of the compressor in making the fuel-air mixture more homogeneous. It is now known that this is by no means necessarily the case, and that in fact a supercharger may often make matters worse. The greater heights attainable with aircraft fitted with supercharged engines also cause further distribution troubles owing to the exceedingly low temperatures encountered, there being a tendency for liquid petrol to be deposited in droplets on the walls of the induction pipe. This is not only extremely detrimental to economy, but on occasion becomes so serious as to cause the engines to cut out completely. The trouble is being attacked by the mechanical breaking up of the droplets of liquid petrol or by heating of the induction pipe, but until it is completely overcome it cannot be economical to fly at these high altitudes.

There is no doubt that considerable room for a general improvement in distribution exists. Experiments on multi-cylinder engines using gaseous fuel show that reductions in fuel consumptions of the order of 20 per cent. could be effected in existing engines if uniformity of distribution could be obtained. Further experiments in this direction are at present being made on an aero engine similar to that tested on the bench on weak petrol-air mixtures, and should give some interesting comparative results.

Variable Ignition

We have shown that it is indicated by bench tests and by the few flight tests that have been made in this connection, that to secure maximum economy it is necessary to advance the ignition as the engine is throttled. The degree of improvement in economy attainable by this means has not yet been established, as the tests made so far have been few, but if the further tests now in hand bear out the indications given by those already made, an advance of ignition on throttling will be well worth while.

If variable ignition is to become standard it will almost certainly have to be automatic in action, as the addition of yet another engine control in aircraft cannot be contemplated. It is not at all easy to find a satisfactory way in which this automaticity can be achieved, for more than one factor is involved. If the advance is determined by the rate of rotation of the engine, in such a way that the spark is advanced as the r.p.m. fall, the correct effect is obtained when cruising, but the ignition will be retarded for level flight at full throttle, which is undesirable. It has been suggested that the induction pipe depression might be used, so that the ignition advance is determined by the load on the engine, but this method of control would be difficult to apply to supercharged engines. A combination of the two methods is what is really required, but this would be somewhat complicated, especially as some additional arrangement would have to be made to retard the ignition while the engine was idling. The difficulties in the way of fitting automatically variable ignition therefore may be such as to outweigh the advantages it brings.

Other Lines of Development

There are, of course, other ways in which petrol engines may develop in the direction of securing greater economy, but it seems that those already mentioned are the most likely in the more immediate future for the engines of normal types of aircraft. For special long range aircraft special high compression engines and special non-detonating fuel will, we imagine, continue to be used, and possibly other ways of obtaining economy discovered and developed. There is, of course, the direct injection engine, so attractive in theory and holding out hopes of eliminating carburation, compensation and distribution troubles, but still in a half-developed stage. There is also the compression ignition engine, with its promise of low specific consumptions, but with an inevitable increase in weight. Each of these may bring problems of range and height in its train. As far as this paper is concerned, however, we feel that sufficient for the day are the engines thereof.

Effect of Wind on Altitude of Flight

In all the foregoing, discussion has been confined to flight in still air, on the ground that wind is more the concern of meteorologists than of the present authors, and also because it is considered that it is necessary first to find out to what extent height affects the range of an aircraft in still air in order to be able to assess the relative importance of wind. The work that has been done so far indicates that the variation of range with height that may occur under normal conditions of flying is rather indefinite, but that as more economical conditions are attained, so the range tends to vary less with height. Hence the variation of wind speed with height becomes of increasing importance as economy is improved.

One point often overlooked in discussing the effect of wind is that since the range of an aircraft is a function of the indicated air speed, the important factor as regards wind is not the true wind speed (v) but what may be called the "indicated" wind speed ($v\sqrt{\sigma}$), and it is therefore the variation of this with

height with which we are concerned. If therefore we have an economical aeroplane of which the range in still air is constant with height, unless the rate of increase of wind with height is greater than that of $1/\sqrt{\sigma}$ no gain in range is obtained by flying high with the wind and low against it.

There is a popular impression that the speed of the wind invariably increases with height. While this is true in the case of relatively strong winds, the variation of wind speed with height in the case of light winds, particularly in anticyclonic conditions, is so complex and depends on so many factors that meteorologists are loth to generalise about it. It may, however, be said that on nine-tenths of the days of the year there is an increase of wind between sea level and heights of the order of 15,000 ft., an increase greater than that of $1/\sqrt{\sigma}$, and on three-quarters of the days of the year there is an increase of the same order between sea level and about 10,000 ft. At lower heights than this the wind variation is very indefinite, and with light winds appreciable decreases with height frequently occur. It will be seen, therefore, that, while there is some foundation for the popular view that wind increases with height, it must be applied with discrimination in any particular case.

Conclusion

In conclusion we would summarise:—

At the present time fuel is wasted and range curtailed by the use of unnecessarily rich mixtures. This is mainly due to insufficient use of altitude control.

The range attainable by an aircraft to-day is largely in the hands of the pilot. Widely differing consumptions are often obtained on the same aircraft when attempting identical conditions.

In our opinion, limitation of the movement of the altitude control in aircraft might well be discontinued.

The damage that can be caused to engines by the use of weak mixtures has been greatly exaggerated.

It appears that, in general, modern water-cooled engines may be run on weaker mixtures with safety than may air-cooled engines.

Weakening the mixture until a 3 per cent. drop in r.p.m. occur in level flight has, so far, given the lowest consumptions on flight tests. This is in agreement with test bench experience.

When running on weak mixtures it seems to be advantageous to advance the ignition as the engine is throttled.

For really economical running, precise adjustment of the altitude control is required. The development of automatic A.C. is necessary to attain these conditions in routine flying.

Improvements in carburation and distribution are needed, especially with a view to improving the economy when throttled.

Under average conditions of flying, the mixture strength is so indefinite that it is impossible to predict with any accuracy the range at any height. This state of affairs is clearly unsatisfactory.

The work done up to date indicates that as economy is improved, so range becomes more nearly constant with height. Theory indicates that for maximum economy range should not vary with height.

For maximum range flight should be made at a constant indicated air speed at all heights. Hence it will always save *time* to fly high.

Wind, by no means a negligible factor at the present time, is likely to assume even greater importance in the future.

Acknowledgments

We should like to thank all those individuals and firms who have assisted us in the preparation of this paper, especially certain members of the Staffs at the R.A.E. Farnborough, the A. and A.E.E. Martlesham Heath, and the M.A.E.E. Felixstowe. Our acknowledgments are due to Mr. H. L. Stevens, Chief Technical Officer at Martlesham Heath at the time of the flight tests. We have also to thank the Air Ministry for permission to read this paper and the Comptroller of H.M. Stationery Office for permission to publish many of the illustrations. Finally, we are required to state that all opinions expressed are our own and do not necessarily carry any official sanction.

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Discussion

The Chairman: The authors were very much to be congratulated both on the consistency and thoroughness of the experimental work they had carried out, and also on the very businesslike way in which they had put the results forward. A public discussion on a question of this kind was a matter of the greatest value, because it could hardly be questioned that the phenomenal development in aero engines as regards their power-weight ratio and their reliability had not been accompanied hitherto by a corresponding improvement in fuel economy. The question was one of interest from many points of view. There was, for example, the national and financial point of view. The annual fuel bill for the Royal Air Force last year was £672,000, and a saving of 10 per cent. on that meant, roughly, a saving of £67,000 a year. That might not make any difference to the income tax, but it would buy quite a number of new aeroplanes; and that would mean a transfer of the money from the pockets of the oil companies to the pockets of the aircraft constructors.

The subject was exceptionally interesting, both from the theoretical and practical aspects. It was useful to emphasise the theoretical aspect because this problem, which was almost entirely an engine problem, was one which illustrated what should be the proper attitude of the engine man, namely, to keep his roots in theory and at the same time to develop a profound respect for practice. Perhaps he might expand what he meant. As the authors had pointed out, the aerodynamics of the problem were comparatively simple. To get maximum range there was a certain indicated air speed at which the machine should fly, and that was the same for all heights. If the machine was flown at that best indicated

air speed, the range which would be obtained depended entirely on the fuel consumption per b.h.p. hour. Starting from single-cylinder experiments it was found in the laboratory that, provided the most economical fuel-air mixture was used, together with the optimum ignition timing, the indicated thermal efficiency of the engine was almost exactly constant during a test carried out at constant speed, but with smaller and smaller throttle openings. If flying trials were carried out at two different heights at the same indicated air speed, the engine would be much throttled near the ground and less so at high altitude. Working, therefore, from the basis of the laboratory experiments *via* the indicated h.p. of the engine, and knowing how the pumping losses vary with the throttle opening, and the friction losses vary with the speed—both of which were known with a reasonable degree of accuracy from experiment—it was possible to conclude that the fuel consumption per b.h.p. hour at different heights would be substantially constant, and it therefore followed that the range at the appropriate indicated air speed would be independent of height. As the authors had pointed out, the early tests did not confirm that theoretical result, but in the later tests it was shown that the nearer we got to using a truly economical mixture, the more nearly was a constancy of range with height fulfilled. The importance of that, it seemed to him, was that it gave one confidence in the application of engine theory. He himself had always been convinced that the apparent discrepancy between theory and practice was due to failure to operate an engine in the air at anything like the optimum conditions of mixture strength and ignition timing.

This led him to the practical side of the question, and to why it was not always possible in practice to operate under these most economical conditions. The answer depended ultimately on the fact that an engine would give its full power on a mixture which was substantially richer than the complete combustion mixture. Moreover, it would go on giving practically the same power through a very wide range in mixture strength on the rich side. Engines had been developed to give the maximum power possible, but owing to this constancy of power with mixtures up to 50 per cent. rich, they had naturally been developed to require, when giving their maximum output, a richer mixture than the most economical one, since this provided cooler cylinder conditions. It was not in the least to the discredit of the aero engine that this should be so. If the aim was to get maximum power, the engine was naturally developed to do so under the conditions in which it could operate most safely and without overheating.

As to how far it was possible to go on running an engine on weak mixtures in the air, was a controversial point and was likely to remain so for some time. The authors had said that the engines could be run on " appreciably weaker mixtures " than at present. With that he could agree, but he was not sure that he could agree that engines could be run on appreciably weaker mixtures and yet give full power. Under cruising conditions it might be so; but it was one thing to agree to a generalisation of that kind and another to allow practical conditions to be such that much weaker mixtures could be introduced forthwith, when, in point of fact, we did not yet know for certain how weak we could safely go. The direction in which engine development must proceed was to discover how weak in practice it was possible to go without danger to the engines after prolonged running, because it must be remembered that in practice the aim was not for engines to run for 100 hours, but for 500 hours, without needing attention. With regard to the interlinkage of the altitude control, so called, and the throttle, to which reference had been made in rather forceful terms by the authors, it occurred to him—and he put it forward as a query rather than as a statement—that the interlinkage was not so much because of fear of damage from excessively weak mixtures, but from fear of the altitude control being left open when the pilot suddenly throttled down. In that case the pilot was in danger of losing

his engine altogether. The interlinkage ensured that, if the pilot suddenly throttled back, the altitude control was closed with the throttle and the danger of the engine cutting out was avoided. That was a point which was not mentioned in the paper.

Continuing, the Chairman said he would like to say a word about what seemed to him the ideal to be aimed at, namely, the development of automatic altitude control. This would mean an automatic arrangement to look after the influence of the height upon the carburettor, and at the same time a carburettor with a characteristic which would look after the question of giving the appropriate mixture for each throttle setting at any height. The development of such an automatic arrangement was a problem on which the Air Ministry was very much engaged at the present time, and was at least within view of achievement. Until that automatic compensation for altitude was achieved it was necessary to continue with the hand-operated control which, however, it would be a good thing to agree to call a mixture control. He entirely agreed with the authors in their deprecation of the expression " altitude control " because it was in fact a mixture control which could be used at all heights with advantage. The reason why carburettors had not got the ideal characteristic with regard to different throttle openings was that there was not sufficient incentive to obtain this ideal carburettor characteristic so long as there was a hand-operated mixture control; because, in these circumstances, the mixture would always be dependent ultimately on the position of the mixture control. The ultimate aim must be a carburettor which gave the rich mixture needed by the engine for full throttle operation, and a mixture which gradually weakened off to give the safe weak mixture for cruising conditions; always provided that it could give the necessary rich mixture for sudden acceleration. With regard to the sudden fall off of range at air speeds above the optimum one at 15,000 feet, pointed out in the paper, it occurred to him that that might be due to the fact that at 15,000 feet, where the air temperature would be lower than at any other height, as the throttle was opened, more and more petrol was taken in, but only a proportion of it was satisfactorily vaporised and used. There was a good deal of evidence that in some circumstances liquid petrol went right through the engine from induction to exhaust without being properly evaporated. When this was so the engine was really dependent for its power on the more volatile fractions of the petrol, and this would give the effect of a much more rapid increase of petrol consumption than if all the petrol had been properly evaporated and completely burned.

There were two other small points he would like to mention. One was that he did not think that it was fair to suggest that it was as easy to check the mixture strength from readings of an r.p.m. indicator as to check the boost pressure by the boost gauge. The latter was an instrument which gave a definite reading and was not likely to lie, whereas the reading of an r.p.m. indicator would depend upon whether the machine was flying level or not, and in unskilled hands might be quite unreliable.

His last point was that the use of gaseous fuel had been mentioned by the authors as having given evidence of the possibility of a reduction in fuel consumption of 20 per cent., through improved fuel distribution between the cylinders. That, however, was a dangerous statement to make, because the thermal efficiency of an engine depended on the actual type of combustible that was used. It was possible to get a higher intrinsic thermal efficiency when employing a gaseous fuel, and this might give a deceptive appearance of lower consumption in so far as it would be incorrect to ascribe the whole reduction to improved distribution, as compared with that when using a liquid fuel.

(*Communicated.*)—Later in the discussion Mr. H. L. Stevens queried the suggestion that the lost M.E.P., and therefore mechanical efficiency of the engine, would not be very different at 15,000 feet from what it was at 1,500ft. when

throttled so as to give the same indicated air speed. As this is a matter of some general importance, he had looked up a number of test results and should like to add his conclusions.

The r.p.m. in these tests at the optimum, V_i, 75 m.p.h., were about 1,300 and 1,600 at 1,500ft. and 15,000ft. respectively. An average figure for L.M.E.P. at 1,600 r.p.m. ground level, at full throttle would be 14.5lb./sq. in., and from motoring tests it is found that the figure 14.5 would diminish about 2.5lb. per sq. in. between 1,600 and 1,300 r.p.m. At 15,000ft. the full throttle r.p.m. were 1,760 and the B.M.E.P. must have been about 0.55 of the ground level value, say 65lb. per sq. in. At $V_i=75$ the corresponding values would be 1,580 and 54lb. per sq. in. When flying throttled at 1,500ft. the B.M.E.P. would be the same 54lb. per sq. in., since at all heights it is the same for the same V_i. Aero-engine tests in N.A.C.A. Report No. 262 show that throttling to this degree gives an increase of *pumping* loss of about 4lb. per sq. in. at ground level; and further tests in the same report, as well as others in Report No. 108 of the same series show that, at full throttle, the pumping loss would decrease at 1,600 r.p.m. by about 2.5lb. per sq. in. between 0 and 15,000ft. Allowing for the throttling at this height when $V_i=75$ we may fix the pumping loss as probably 1.5lb. per sq. in. below the full throttle, ground level, value. There would also be some reduction in mechanical friction loss on account of reduced gas pressures, but the reduction would be the same whether the engine was at 1,500 or 15,000ft. since the B.M.E.P. was the same. The reduction may be fixed at 1.5lb. per sq. in. since it can be estimated that at full power the friction which varies with gas pressure is about 3lb. per sq. in.

They then had

L.M.E.P. full throttle, ground level, 1,600 r.p.m. = 14.5.
,, throttled, 1,500ft., 1,300 r.p.m. = 14.5 − 1.5 − 2.5 + 4 = 14.5.
,, full throttle, 15,000ft., 1,600 r.p.m. = 14.5 − 1.5 − 2.5 = 10.5.
,, throttled, 15,000ft., 1,600 r.p.m. = 14.5 − 1.5 − 1.5 = 11.5.

These figures assume that the mechanical friction at 15,000ft. will be the same as when throttled at ground level, at the same r.p.m.; in other words, that the oil viscosity under the two conditions will be the same.

As stated above, the B.M.E.P. of the engine at $V_i=75$ m.p.h. will have been about 54lb. per sq. in. throughout, so that the above change of L.M.E.P. between 1,500 and 15,000ft. corresponds to an increase of mechanical efficiency from 79 per cent. to 82.5 per cent.

The figures given are necessarily somewhat speculative, but are probably sufficiently accurate for one to conclude that an increase of about 5 per cent. in mechanical efficiency is to be expected, at constant V_i, between ground level and 15,000ft. The amount was more than he had expected, and he was obliged to Mr. Stevens for drawing his attention to the magnitude of the effect produced by the variation in pumping losses.

Major F. M. GREEN: The paper was very encouraging because it indicated that the theories on which they had worked so far proved to be correct in practice. Thermal efficiency, which was the same thing as petrol consumption, depended, in a petrol engine, mainly upon four factors. The first was the shape of the combustion space, and this is fairly constant in all engines. The second factor was the mechanical efficiency of the engine, and here again he did not think that various types of engines differed very much, except that radial engines were probably a little more efficient than in-line or Vee engines. Next there was the question of distribution, and in this respect there was some difference between different types of engines, but generally not enough to make a serious difference to petrol consumption. He was surprised to hear that any engines were worse supercharged than unsupercharged, because in his experience the radial type of engine was always improved by supercharging. Finally, the factor which had

the greatest influence on petrol consumption is the compression ratio. Presumably all engine builders designed for the highest ratio that they considered safe, and that was governed very largely by the worst fuel on which the engine might have to work, and also upon the number of hours between overhauls that the engine was expected to run. Water-cooled engines might be expected to work to a slightly higher compression ratio than air-cooled engines and consequently the petrol consumption ought to be, and generally was, slightly better, although this was sometimes offset by the improved mechanical efficiency and distribution obtained in radial engines. It is generally believed that air-cooled engines have considerably worse consumption because on full throttle it is necessary to use an over-rich mixture in order to get the maximum power. As the range of an aircraft was governed by the consumption at part throttle this had practically no effect, as it was not necessary to use an over-rich mixture at lower power.

Coming to the importance of getting the best out of an engine, this depended somewhat on the carburettor, but, as the Chairman had said, it depended much more upon the pilot. It was almost certain that an automatic mixture control working according to altitude would come into use in the near future. Meanwhile, an intermediate step might prove useful. At the moment he was concerned with an aeroplane with four engines in which it was necessary to keep the mixture strength normally accurate. It seemed unfair to ask the pilot to adjust the mixture strength of each engine independently. The method to be used is to connect up all four mixture control cocks together and to operate them from a single lever in the cockpit. The carburettor maker had undertaken to mark the cocks in thousands of feet, and it was only necessary then to make sure that each cock was opened to the right marking, corresponding to a similar marking on the lever in the cockpit.

Carburettors in the past had had entirely unsuitable characteristics, due chiefly to the fact that petrol consumption on official tests was always measured at nine-tenths of full throttle, and nobody worried much about what happened at a lower power than this. Carburettors, therefore, used to give a weak mixture at full throttle and an increasingly rich mixture at part throttle, which is, particularly for air-cooled engines, exactly what is *not* wanted. Fortunately it had been possible for makers of modern carburettors to give us the required characteristics, and now it is possible for a pilot to get a strong mixture for taking-off and a weaker mixture directly he throttles down. The next step was to arrange the altitude control, or the mixture control as it is better called, so that it gave the same characteristics as the machine gained height; and this again seems to be quite possible. If the mixture control is worked automatically, then we ought to get very close to the lowest consumption that is possible in all conditions of speed and altitude.

Finally, on the question of the weakest mixture that it is possible to use without damaging an engine, his own experience is that the engine gets hotter as the mixture is weakened down to the chemically correct mixture. After this he was not certain what happened, but was inclined to believe that the engine on the whole became slightly cooler as the mixture became still weaker. At part throttle the increase of temperature was generally not serious, but there were two things which at present limited the use of very weak mixture. One was the behaviour of the sparking plugs, which for some unknown reason did not seem to work well on a very weak mixture and seemed to require cleaning much more often; and the other was that the piston rings seem to gum up quicker with a weak mixture. The reason for this is not entirely understood, but experience has shown that when running on a rather weak mixture piston rings were likely to gum up after 300 hours, whereas with a stronger mixture they would run double the period. He mentioned three engines which had just been examined

from one aeroplane which had run for 600 hours, cruising from 70 to 80 per cent. of their normal power without any cylinders being removed. There was no sign of piston rings sticking, and the engines generally were in excellent condition. If the engines had been run on a weaker mixture it is probable they would have needed more attention, and the saving in fuel might perhaps have been more than offset by the increase of expenditure on overhaul. Investigation was going on actively on the subject, and he had very little doubt that in the near future they would find means of running engines on the most economical mixture without sparking plugs giving trouble or piston rings sticking, but until they were quite sure that they could do this it was not safe to experiment on aircraft in which reliability was the first essential.

Mr. H. L. STEVENS: He congratulated the authors on an extremely interesting paper on a very difficult subject. The paper emphasised the wisdom of the policy of having a small research staff at testing stations. The origin of the work described in the paper might almost be considered as an effort to reduce the number of tests which had to be made at Martlesham. It was found that it was not easy to get consistent results among different observations and therefore the endeavour was made to arrive at some system which would give consistency among observations carried out at different heights in order to avoid making too many repeat observations. One result of the first report on the subject was an official request to carry out a great many more experiments as the first results conflicted with existing theories on the problem of fuel economy in the air.

He felt he must quarrel to some extent with the remark of the Chairman that the specific consumption of an engine must tend to remain constant with height. It did not seem to him that that would be so; there must be a tendency for the specific fuel consumption to fall off with height and that favoured the original theory that it paid to fly high. The reason for that was that as the engine torque at constant indicated speed was constant, the frictional losses would be proportional to the engine torque and they would go up with revolutions. The power that was being used went up in the same proportion and therefore the frictional losses would remain the same proportion of the power; this would make no difference to the specific consumption, but the throttling or pumping losses would be greater at lower heights because of the restriction caused by throttling. Therefore, in general, it seemed to him that the specific consumption should tend to decrease slightly at height, and so the over-all efficiency should increase to a certain extent.

It would also pay to fly high against a wind if the wind did not increase with height, because the actual speed through the air was greater and therefore the effect of the wind less marked.

Mr. HOLLIS-WILLIAMS (Fairey Aviation Co.): There were one or two points based on the work done by the Fairey Aviation Company on the long range monoplane which might be of interest. They started out with the theory that the range would be independent of height. After making careful tests they thought they had traced an increase of specific consumption with height and thought that this was due to the frictional losses which were opposing and overcoming the rest of the factors which caused increased consumption at height. Their final view, however, was that the effect on specific consumption of altitude was small and that other factors, notably engine vibration and increase of intake temperature, were vastly more important. Thus, on the long flights of the Fairey monoplane it had been found that the specific consumption registered, when the machine was flying low soon after the start at a heavy power output under conditions particularly conducive to good consumption, was equalled towards the end of the flight when the machine was flying high at small power output. He put this down to the reduction of vibration with throttle closure, vibration having a

bad effect on the weak unstable mixture, and to the general increase of atmospheric temperature as the machine approached tropical climates.

Another point was in connection with future development. An important point that had not been touched upon by any other speaker was the increase of range due to airscrew design, especially in relation to the improvement of range made possible by the variable pitch airscrew. For ordinary full throttle performance it was not absolutely certain that the V.P. airscrew was worth the complication except in particular cases, but for long distance flying the variable pitch airscrew came into its own. In addition to an increase in efficiency, which continued to improve with considerable increases of pitch, there was the second benefit from reduced frictional losses due to the use of higher M.E.P. If a 500 h.p. engine was being used, for example, and at any particular moment only 200 h.p. was required it was possible, by putting up the braking effect of the airscrew, to get a much higher mean effective pressure in the cylinder and get in the limit to what would be full throttle at 200 h.p. That, he believed, was an indication of a development which would give the biggest increase in range in the near future.

Mr. Dobson: The authors in referring to the altitude control by the pressure system, had described an obsolete type, because the system mentioned in the paper was not the type now used on A.V.T. 70 G. The latest type did not operate quite as described. The altitude control really operated by allowing air to enter the emulsion passage and to dilute the emulsion as it came from the diffuser, and it had been found that that type of altitude control displaced the throttle curve, practically speaking, parallel, *i.e.*, it had no greater effect at the high speed end of the throttle curve than at the lower speed end, and that was of very great importance, and probably essential for the successful development of automatic altitude control.

Captain Swan: The first three conclusions dealt with the waste of fuel and the use of altitude control. Much of this wastage could be avoided even with a bad carburettor if the mixture control was used properly. If the wastage continued then it was obvious that the Air Ministry's Instructions with regard to the use of the control were being disregarded. Interference was another cause of wastage, but that was disappearing in the later types of aircraft and he could not conceive any reason why it should occur now to any extent. If interference of the throttle lever still caused a limitation in the range of mixture control it would seem to be due to a mere stupidity on the aircraft maker's part in wrongly connecting the controls in the cockpit to upset their proper and relative operation. On the question of stops, he agreed with the Chairman that the intention was to provide against the forgetfulness of the pilot rather than against his deliberate action. At the same time it must be generally agreed that automatic control would remove all the existing difficulties.

With regard to damage to engines due to running on weak mixture, he agreed that this had been exaggerated, but not greatly exaggerated, as suggested by the authors. It was reasonable to press for a greater economy, but it might be premature to insist, on the basis of one or two isolated tests, that all engines should be run at these particular economic consumptions. There should be some continued development by way of tests on various engines and that, of course, would take some time. He had taken some readings of cylinder temperatures under various throttle conditions and with various mixture strengths and, as might be expected, the cylinder temperatures were higher at full throttle and they were about the highest at the correct mixture strength, whilst they were slightly lower at the richer mixture giving full power. This latter was due to the cooling effect of the petrol. At any throttle opening the temperatures were usually higher at just about the correct mixture strength, though not so high at part throttle openings as at full throttle, and they became lower as the mixture was weakened

for any throttle position, so that from the cylinder point of view it would appear reasonable to run on weak mixtures particularly under throttled conditions. What appeared most noticeable was the excessive heating of the exhaust valve. Whilst the cylinder might be cooled with weak mixtures the engine exhaust valve was liable to be heated, due to the slower rate of burning.

In one of the conclusions the authors rather suggested that the optimum conditions for a range were obtained at a percentage reduction of 3 per cent. in the r.p.m. Results of tests very definitely showed that the economy of range was linked up with mixture strength, but it was possible that some other mixture strength might give better results. At Farnborough, in the course of work on carburettor calibrations, data had been obtained which appeared to be relative, and although they had not been examined closely from this point of view the evidence seemed to show that with mixtures weaker than were obtained with a 3 per cent. reduction in r.p.m., the range was increased. Whether the range remained constant for all heights at these weaker mixtures was quite unknown at present from these experiments.

One other small point was that the authors in their conclusions stated that with weak mixtures the ignition could be advanced under throttled conditions. The curve the authors showed illustrated that for weak mixtures a greater advance than the standard fixed ignition could be used, but there was no indication in those curves that this advance varied as between full and part throttle.

Mr. MANNING: As the lecture had been concerned mainly with range from the point of view of the engine, perhaps he might say something with regard to the same matter from the point of view of the aeroplane. Fundamentally the energy which was utilised by an aeroplane flying from one place to another was simply the resistance of the aeroplane multiplied by the distance, and from that it followed that the maximum range of an aeroplane was proportional to the total available energy divided by the resistance. As the total available energy was proportional to the fuel carried, it followed that the range of an aircraft was proportional to the fuel carried divided by the resistance. If from the total amount of fuel carried was deducted the proportion representing the amount not converted into useful work by the engines and propeller, the amount remaining divided by the resistance was the distance the machine would fly. If a machine was flying say at minimum resistance, that resistance would be the same at all heights, but the speed would be greater according to the altitude. Therefore at heights the machine would reach its objective more quickly than at ground level, but its range would be the same, so the advantage of flying at heights would be a saving of time.

With regard to the diagrams showing speeds, he took it that these speeds were indicated and were not corrected for height. In most of the more modern French engines multiple carburettors were used, as many as six carburettors being used for 12-cylinder engines. That, of course, was done to improve the distribution, and in time he would not be at all surprised to see one carburettor per cylinder on the French engines. The only other point he wished to make was to ask how many of the present engine troubles would disappear when the Diesel engine came along, although no doubt that engine would bring a few troubles of its own.

Mr. LOVESEY: The degree of weakness of mixture on which an engine would operate satisfactorily depended largely on the output which was demanded from the engine. He had in mind a water-cooled engine operating with a B.M.E.P. of about 140lbs. per square inch and would work most satisfactorily, and at its point of maximum fuel economy without the slightest sign of distress either from sparking plugs or valves. Another supercharged water-cooled engine, however, with a high degree of boost, and a brake mean effective pres-

sure of from 250lbs. to 300lbs. per sq. inch, would not approach the condition of maximum fuel economy without experiencing pre-ignition trouble from hot exhaust valves. In this particular case the engine could be run at a consumption of .64 pts./h.p./hr. as long as was desired, but if that was cut down to .6 there was pre-ignition due to the hot valves. That same engine using sodium-cooled valves could get down to .56 and work quite satisfactorily. Comparisons between the air and water-cooled engines with regard to operating at maximum economy were rather parallel to this case. It could be said that the highly boosted water-cooled engine would be somewhat similar to the only moderately boosted air-cooled engine as regards the extent to which it was possible to go with weak mixtures without running into overheating troubles. In other words, with reasonably high power output the water-cooled engine would be able to operate satisfactorily nearer its point of maximum fuel economy than the air-cooled engine. He agreed that the greatest heat flow to the water jackets seemed to take place when using a mixture which just permitted the attainment of maximum power. By increasing the strength of the mixture the heat flow was decreased, and by decreasing the strength of the mixture the heat was increased. Another question in connection with minimum consumption tests was the effect of water temperature. He had known as much as 17 per cent. gain in economy when running under boiling conditions as compared with running at a temperature of 60°C.

The question of the effect of altitude on economy: Would not a definite gain in specific consumption be obtained at high altitudes by the gain in power due to the reduction of atmospheric back pressure on the exhaust?

Squadron Leader S. N. Cole: He had gained some experience in this matter. In Iraq, in the Middle East, cases had occurred where it had been of first importance to obtain the greatest practical economic range, *i.e.*, the minimum consumption for a given live load carried. In several types of aircraft the range was increased considerably without noticeable effect on the life of the power units.

In the Service, at home, this matter was investigated with aircraft used for communication purposes. Types of engines in use were Cirrus, Falcon, Napier and Liberty, and as these engines came out of their aircraft for overhaul, replacements were effected by engines on which adjustments to reduce petrol consumption had been made whilst they were on the test bench.

After 18 months' work he discovered that the man hours required on overhaul went *down* very considerably, whilst it was possible to lay down new regulations for running inspections, etc., which resulted in a greater number of running hours being completed before it was necessary to remove engines for overhaul.

Over the period in question, for a given number of flying hours, there was a reduction of 5 per cent. in fuel consumption together with an increase of approximately 12 per cent. in total running hours before overhaul.

Very definite care and maintenance instructions were laid down for all types of engines in use, and in this connection it was worthy of note that it was found necessary to reduce the limiting of change, as against standard settings, for sparking plug gaps, valve clearances and timing, controlling actual valve movements. As an example, it was found necessary to remove plugs and re-set gaps on two types of engines after 15 hours only.

Mr. Scott-Hall: One point which had not been mentioned in the discussion was the difficulty experienced in fitting flowmeters into the petrol systems of many aeroplanes sent for official trials. One realised the difficulties manufacturers had in making their petrol systems suitable for this adaptation, but much valuable information could be obtained on the subject of consumption if it could be made possible in all cases. He heartily endorsed what the lecturers had said on the subject of carrying out a consumption test by running a tank dry. The

method was not accurate, and some idea of the time required could be obtained from the fact that one point on the consumption curve could only be obtained after some 45 minutes flying, whereas the same information was given by the flowmeter in two minutes.

Flying Officer WHITTLE: He did not think the average pilot realised how very important this subject was, and it was to be hoped that the conclusions arising out of this paper and discussion would eventually reach the average pilot, because there were occasions when the difference between ignorance and knowledge on this subject might mean the difference between life and death. One example would serve to illustrate this point. He knew one pilot who went in a single-seater land plane up to 20,000ft., above an unbroken cloud layer, and presumably he was rather careless about his direction up there, because when he eventually descended through the clouds, he found himself over the sea with no land in sight. After hastily deciding that he was over the North Sea, he flew in a westerly direction at full throttle. Luckily he just succeeded in crossing the coast before his engine failed. That was a case in which the pilot knew that he had been in the air for a long time, and that his fuel must be getting low; he also knew that he stood an excellent chance of being drowned if he did not reach dry land, and yet he flew at full throttle. That example, which was not unique, emphasised the importance of the problem of range as far as the pilot was concerned. The average pilot did not realise that the speed of maximum range under still air conditions was usually very low. This led to the question of speed, which should always be coupled with range (in his opinion). It was an unfortunate fact that range could only be obtained at the expense of speed at low altitudes, and vice-versa. However, there was a saving factor in height. By flying high the combining of desirable speeds with desirable ranges became more possible, so that if we desire to both go a long way and to go quickly then we must fly high.

One important question which had arisen during the paper and discussion was that of the effect of the supercharger in the induction system. The authors had mentioned two factors which had a deleterious effect on the distribution. They stated that the supercharger might have a bad effect where fitted, and also that the low temperatures experienced at high altitudes have a bad effect on distribution. It seemed that in the case of supercharged engines, the obvious remedy was to put the supercharger on the " air side " of the carburettor, so that the carburettor and induction system would receive air warmed in the compression process of the supercharger. This seemed the most natural way of supercharging, and it should cause conditions in the carburettor and induction system to be more nearly corresponding to ground level conditions than at present. Incidentally, Major Green had stated that in his experience the supercharger had invariably had a beneficial effect, but personally he would suggest that in those particular cases, the beneficial effect was in spite of the supercharger rotor rather than as a result of it, because it seemed that if the rotor was to have any effect at all on the mixture it would be that of a centrifugal separator rather than a mixer, particularly if the petrol were in the form of mist or droplets.

Mr. W. S. FARREN (*communicated*): He wished to congratulate the authors on their admirable paper on a subject which is not only of the greatest practical importance on account of its bearing on the operational powers of aircraft, but also of the highest technical interest. If any further inducement is needed to carry on the good work in which the authors have been intimately concerned, it is supplied by the reduction of the fuel bill of the R.A.F. which would result from a really practicable solution of the main problem—the intelligent regulation of the strength of mixture supplied to the engine.

The Range of Aircraft Panel of the A.R.C., of which he was chairman, succeeded in reducing the points upon which any real divergence of opinion

existed to one—could a test be devised which would settle whether the essential characteristic of an average aircraft engine *in flight* was what would be expected from theoretical considerations and test bed experiments? The " weak mixture " tests on the " Stag " referred to by the authors were the result, and they do undoubtedly establish that the consumption of fuel per b.h.p. hour is a function of the torque (or b.m.e.p.) only, and practically independent of height—always providing, of course, that no fuel is admitted in excess of that needed to combine with the air taken in by the engine.

The practical problem then becomes clear—to provide either (*a*) an indicator or (*b*) an automatic control of mixture strength. The method used in the tests is unsuitable for everyday use, especially in formation flying. To fly at a given height at some predetermined indicated (or true) speed involves a definite speed of rotation of the airscrew. Any system using the engine speed as an indicator is therefore clearly unsuitable. A fuel flowmeter, associated with preliminary calibrations and suitable directions to the pilots, would probably solve the problem, but it appears that the R.A.E. flowmeter is not suitable for such a purpose. An automatic carburettor (*i.e.*, one in which a rational throttle characteristic is combined with automatic compensation for altitude) would be a complete solution. But until this is available it would seem that it ought to be possible to *calibrate* the compensator setting in terms of altitude and ask the pilot to perform the functions of the absent automatic mechanism. It should be emphasised that to attain the absolute minimum consumption is out of the question—what we need is a means of securing approximately the " chemically correct " mixture, and of avoiding what occurs at present—the use of mixtures anything up to 30 per cent. or 40 per cent. rich.

It is perhaps rash to suggest a possible alternative form of flowmeter. To produce the R.A.E. instrument—which so far as he knew was the only really satisfactory one in existence—took a great deal of time and effort. But it is hardly a practicable " dashboard " instrument. Is a Venturimeter quite out of the question? A flow of 20 gallons per hour through say a $\frac{1}{2}$in. pipe is equivalent to a speed of 2/3 ft./sec. If the throat diameter were $\frac{1}{8}$in., a pressure difference of the order of 17in. of water would be available, or about the equivalent of the pressure operating an air speed indicator at 160 m.p.h. With a suitable expanding cone, involving a length of 6in. or 8in., the resistance to the flow would be negligible. It may be that pulsations of flow, air locks, etc., would make such an instrument useless, but it would be interesting to know whether it has been considered.

Mr. F. Rodwell Banks (Ethyl Export Corporation) (*communicated*): The paper is essentially one dealing with " fuel economy " and too little has been done, up to date, to try and effect a real reduction in the specific fuel consumption of the high duty aero engine.

Some engine manufacturers are rather prone to quote the high power/weight ratios of their particular motors with little regard to the matter of specific fuel consumption.

Dealing more particularly with the fuel question, he considered that greatly improved results could be obtained, so far as distribution is concerned, if more work could be done on the development of fuels particularly regarding their distillation ranges and anti-knock values.

It is presumed that the tests in the paper were carried out using the present Service fuel. Now this specification (D.T.D. 134), so far as knock-rating is concerned, can be met either with or without the admixture of benzol/toluol according to the class of base petrol obtainable by the fuel contractors. Therefore, one contractor may be able to meet it with a " straight run " spirit and another will have to use an admixture of benzol or toluol. This will affect the

mean volatility curve and the same results will not necessarily be obtained in a given engine with all fuels meeting this specification but supplied by different contractors.

A distillation range is given in the D.T.D. specification but, having in mind the different characteristics of " straight run " petrols and benzol mixtures, further work should be carried out to see if any improvement can be made in this direction.

For comparative and accurate results on various engines, one would suggest the use of a " straight run " petrol of good volatility, particularly at the following temperatures, 50°C., 70°C. and 100°C., with the addition of tetraethyl lead to bring it up to the desired anti-knock value. The addition of the latter does not affect the volatility of the fuel in any way.

Regarding distribution in supercharged engines; it is undoubtedly true that good mixture distribution can be a difficult matter with this type, and in addition, should a high degree of supercharge be employed, the increased pressure in the induction pipe tends to raise the boiling range of the fuel and does not assist matters.

One would suggest that in order to obtain maximum fuel economy a combination of high compression ratio, say 7/1, and evaporative cooling, together with a fuel of good volatility having an anti-knock value of 87 octane (when tested under conditions of high temperature, 150°C.) will go a long way towards giving the desired results.

High compression ratio will improve the thermal efficiency and lower exhaust valve temperatures, evaporative cooling ensures an even and stabilised temperature, and with a suitable induction system will assist the distribution.

A fuel of good volatility and high anti-knock value enables an engine to operate safely with the " leanest " possible mixture.

The remarks made in the paper upon the control of ignition are timely. Far too little attention has been given to this important point and there are many advantages to be gained by its proper use.

A petrol injection system has been developed in America and very good results obtained. It is, at present, fitted to a Pratt and Whitney engine and is undergoing flight tests.

One would say that the injection system might be less efficient when used on a highly supercharged engine as, if air only is pumped by the blower, the temperature will be raised considerably and the charge density reduced.

Mr. H. L. HALL (Chief Engineer, Imperial Airways, Ltd.) (*communicated*): He was relieved to find that the paper adds weight to the balance against the idea that one must fly very high to obtain the maximum fuel range, *i.e.*, the maximum fuel economy.

He observed that the authors conclude that one of the most important factors in obtaining maximum range is the use of weak mixtures. He agreed with this and also with their suggestion that the ignition should be advanced when weak mixtures are used. He thought that failure to do the latter possibly contributed appreciably to the results which have made most of us fearful of weak mixtures.

On the subject of measuring consumption in flight he would say that he had found the R.A.E. flowmeter to be an unusually accurate instrument when used in the test house and whilst he had no doubt that it can be very useful—particularly in single-engined aircraft—to determine when the most economical rate of petrol consumption has been attained, he was a little doubtful as to its reliability as a means for determining the minimum quantity of petrol required to fly a given distance.

In practice it is reasonably satisfactory to take-off and land on one tank and use another tank for the consumption test. The test tank is completely filled and a measured quantity is drawn off to prevent loss in taxying. The quantity required to re-fill the tank after the test, less the quantity withdrawn to prevent spillage, is the quantity consumed during the test. The test should last at least half-an-hour. He would use this method in preference to relying on deductions made from a number of instantaneous readings of a flowmeter which, as the authors have shown, is liable to fluctuations not caused by variations in fuel consumption.

The authors used an auxiliary petrol tank as well as the flowmeter and it would be interesting to learn whether these two instruments were checked against each other in the air. He thought that a ½-gallon tank did not hold sufficient to give a result that would be really useful in commercial service. On the whole he inclined to the opinion that using the tank method of determining the suitability of the desired economical rate of consumption and the flowmeter to help towards ensuring that that rate is maintained as much as possible in flight will give the best results.

The flowmeter is somewhat difficult to instal in a large modern aircraft—the difficulty of making easily visible to the pilot flowmeters mounted near the carburettors of each of four engines which are about 20ft. behind him can be readily imagined.

He noted the trouble experienced with oiled up plugs when braided cables were used. He did not suppose that this trouble was entirely due to the braided cables, but it is certain that some types of braided cables do seriously interfere with the ignition when rain or mist is present.

He agreed that what leaves the carburettor does not necessarily arrive in the cylinders—this is very noticeable in Europe in the winter. In the East more stable and desirable conditions are obtainable and he thought that further consideration of this subject might help to improve fuel ranges in cold climates. Possibly direct injection of the fuel and adequate control of the temperature of the intake air may some day help considerably in the quest for greater economy, but at present it seems necessary to suffer a definite increase in petrol consumption to prevent engines " fading " in flight during very cold weather.

He had not experienced a difference of anything like 40 per cent. in the consumptions of similar aircraft engaged on similar duties.

He thought that weakening the mixture and advancing the ignition might very well lead to considerable economy in fuel, but it will have to be done very carefully and day by day for at least a year in cold climates before the results would become really useful to air line engineers, because engines working under such conditions are " on the edge " and sudden and considerable changes in atmospheric conditions—such as are commonly experienced in Europe—might push them over the edge with unpleasant results—did the test aircraft become unserviceable as a result of getting its engine too near the edge.

In this connection he would mention that Jaguar engines in " Argosy " aircraft are equipped with cams on the throttle barrels which open the altitude controls at cruising speed; these devices effected considerable economy, but it was found necessary to disengage the cams during very cold weather to prevent recurrence of engines " fading " during flight. These cams were re-engaged when hot air intakes were fitted.

It would be interesting to learn whether the engines used by the authors in their tests—both on the bench and in the air—were equipped with exhaust collectors and tail pipes.

He had not noticed an increased tendency to gummed rings as the result of

weakening the mixture, but this may arise if the weakening is pushed too far. He found that ring gumming often followed the use of the wrong kind of oil and weakening of the mixture followed the gumming of the rings—sometimes with consequent failure of the piston.

He confirmed what Mr. Green said about the excellent condition of three engines, which had been stripped recently after working together in the same aircraft, 600 hours at 80 per cent. of their rated power and good fuel economy. These were Lynx engines and their pistons and rings were in exceptionally good condition. They had not been top overhauled—in fact not a single cylinder had been removed—and they had each run 607 hours 42 minutes without interruption of services resulting from engine deficiencies. So far as he knew this was a unique performance and evidence that air line engineers' demands for still greater endurance between overhauls are not unjustifiable.

Squadron Leader HAYTHORNTHWAITE (*communicated*): *Consumption.*—This term is used in four forms and the result is confusing—(*a*) " consumption," (*b*) " specific consumption," (*c*) " actual consumption," (*d*) " specific fuel consumption." Particular attention is invited to this last phrase which was evidently incorporated in the paper on account of its use in certain engineering circles. It is not only ambiguous but actually misleading, for it does not mean what it says (the consumption of a specific fuel). Consumption expressed in pounds per British brake horse-power per hour is no more " specific " than if it were expressed in kilogrammes per continental horse-power per hour, or in any other units. The point is only raised as presumably the Society is interested in the gradual formation of an accurate terminology, appropriate to the subject. He suggested " ergogenic consumption," not to increase their vast vocabulary, but because there does appear to be a very genuine need for an accurate term to denote this particular meaning of the word consumption.

REPLY TO DISCUSSION

Mr. A. E. WOODWARD NUTT said that he would like to thank all those who had taken part in the discussion and had contributed some valuable information. So many interesting points had been raised that they would have to deal with most of them in writing, and even then he did not think they would be able to deal adequately with them all. He therefore asked the indulgence of any who felt they had been treated cursorily. Some of the points raised had already been answered by other speakers. Some speakers had mentioned important factors affecting range which had not been covered in the paper, and he was glad that they had done so, as the lecturers had made no claim to be comprehensive.

He would like to say how much he had appreciated the admirably concise summing up of the theory and practice of economical flight made by the Chairman. He thought it would add considerably to the value of the paper to be published in conjunction with these comments made by so universally acknowledged an authority on internal combustion engines as Mr. Pye.

He was very glad that the Chairman and several other speakers agreed in disapproving of the term " altitude control," and he hoped that the term would now fall into disuse.

He thought that the Chairman's suggestion as to the original reason for interlinkage between the throttle and mixture control was correct, but he did not think that this applied so much at the present time. Flight-Lieut. Scroggs would quote his experiences in this connection in his reply.

There had been no intention on the part of the lecturers to advocate the immediate and indiscriminate use of very weak mixtures generally, and he was sorry if any had been given that impression. As the Chairman had said, we

do not yet know how far we can go with safety, and considerable development work is necessary before this can be definitely established. On the other hand, we had gone very much to the other extreme, and aircraft were being operated on unnecessarily extravagant mixtures, so that it was reasonable to press for some improvement.

He realised that their suggestion that the present limitation of mixture control might be discontinued was highly controversial, but he suggested that it was not really inconsistent with the statement previously made. If the stops or interlinkage were removed he did not consider that pilots would immediately start running engines on excessively weak mixtures. It seemed to be generally admitted that possible damage to engines was most likely to occur at or near full throttle. On the vast majority of aircraft the time run at full throttle represented a very small proportion of the total running time, and of that small proportion full throttle was rarely used for long periods continuously. When a pilot used full throttle it was because he wanted to get all the power he could from his engine, so that he was not likely intentionally to weaken the mixture to an excessive extent. As far as accidental weakening was concerned, it seemed to him that the roughness of the running of an engine on excessively weak mixtures was likely to give an unmistakable indication to the pilot that something was amiss long before any serious damage to the engine could have ensued.

His main quarrel was with the present system of limitation, the tendency of which was to cause the use of rich mixtures at low throttle openings and weaker ones at large throttle openings, the opposite of what was really required.

There seemed to be general agreement that a complete solution of the problem of getting suitable mixtures throughout depends on the successful development of an automatic mixture control, combined with a carburettor which gives a suitable characteristic.

The Chairman's suggestion as to why the range of the Stag falls off at the higher speeds at 15,000 feet seemed to him to be a reasonable explanation of the phenomenon.

As regards the use of gaseous fuel, he must defer to the Chairman's opinion on this point. The figure quoted was obtained from one of the unpublished reports mentioned, and he did not know whether this book took into account the higher intrinsic thermal efficiency obtained by using gaseous fuel.

The numerical example in Mr. Pye's written communication was extremely interesting, and seemed to give a result rather different from that which Col. Tizard had obtained. The change of mechanical efficiency with height was fairly sensitive to the values assumed for the various losses, and he did not feel competent to judge whether Col. Tizard's or Mr. Pye's assumptions were nearer to the conditions actually arising in practice. He understood that there was a good deal of difference between different engines in this respect.

In reply to Major Green, he was inclined to think that distribution was quite an important factor as regards economy. He agreed that air-cooled engines should be as economical as water-cooled engines under throttled conditions.

In default of an automatic mixture control, he thought Major Green's scheme for marking the mixture control in thousands of feet a good one, so long as it was combined with a carburettor which gave a suitable mixture at all throttle openings, as mentioned by the Chairman. He suggested that the mixture control should then *not* be interconnected with the throttle.

He was interested in Major Green's remarks on the effect of mixture strength on prolonged running, for there was very little evidence which covered so long a period as 300 hours. Major Green's experience seemed to disagree with that of Squadron-Leader Cole. He would have liked to have known what specific

consumptions were obtained with the two mixture strengths mentioned by Major Green.

He would like to congratulate Major Green on the performance of the three (Lynx) engines he quoted, especially as Mr. Hall had subsequently stated that they had run " with good fuel economy." He entirely agreed that one should not experiment on aircraft such as air liners on which reliability was all important.

He especially appreciated Mr. Stevens' comments, as it was due to his reopening of the controversy on the effect of height on range that the present investigation was made.

As regards the constancy or otherwise of specific consumption with height, he thought there was some doubt as to whether the frictional losses went up with revolutions in the same proportion as the power, as Mr. Stevens had stated. Mr. Pye's written communication certainly seemed to bear out Mr. Stevens' final conclusion.

On the question of flying in a wind, actually it would pay to fly high against a wind, even if the wind increased slightly with height, so long as the rate of increase was less than that of $1/\sqrt{\sigma}$. This was the converse of what was stated in the paper.

The conclusions arrived at by Mr. Hollis Williams as a result of his experience with the Fairey Long Range monoplane seemed to be similar to their own, though he did not altogether agree with Mr. Hollis Williams on the subject of vibration. He had experienced very low specific consumptions associated with bad vibration, though admittedly not for long periods. He certainly agreed on the importance of intake temperature, and thought that experiments on this subject would be valuable.

He was glad Mr. Hollis Williams had mentioned the variable pitch airscrew, as he thought that its importance on range was not generally appreciated. In the paper they had had to confine themselves to some only of the existing factors affecting range, and had not been able to touch on future possibilities such as the variable pitch airscrew.

Captain Swan appeared to agree that fuel wastage was largely due to insufficient use of mixture control. He (Mr. Woodward Nutt) thought, however, that Captain Swan was unduly optimistic in suggesting that interference does not occur now to any extent.

He entirely agreed that it would be premature to insist on engines generally being run at the particular economic consumptions used on the tests described, and it was not suggested in the paper that this should be done. Many more tests are required before any such definite recommendation could be made.

He was glad Captain Swan had mentioned the cylinder temperature measurements made at the R.A.E. The results obtained by the makers on other types of engines seemed to agree with these in general.

It was not intended to suggest that weakening the mixture until a 3 per cent. drop in r.p.m. occurred in level flight necessarily gave the optimum conditions. He agreed that possibly some other mixture strength would give better results. On the other hand, the figure of 3 per cent. was no haphazard choice, but was based on extensive bench tests. Also, tests made with this particular mixture strength seemed to give the same range at all heights, and according to Col. Tizard's argument this occurs for maximum economy.

He hoped that the data obtained at Farnborough during carburettor calibrations would be made available, and that information would be included to show the degree of accuracy with which level flight was maintained during the tests.

On the question of ignition advance, the curve shows improved economy at low throttle openings only with an advanced ignition timing.

Mr. Manning's general statement from the aeroplane point of view was very welcome, as there was always a tendency to miss the wood for the trees. It seemed to be as true as any general statement of this nature could be. In the paper, they had, of course, been concerned with that part of the fuel carried which could be converted into useful work, and had shown how in practice the efficiency of this conversion often varied with altitude, with a corresponding effect upon the range.

The speeds on the diagrams are in every case indicated air speeds, and have been corrected for instrument calibration error and for the position error of the pitot-static head only. The engine quoted as giving a particularly low specific consumption might be described as one of the modern French engines, as it was the 650 CV Hispano-Suiza. He was afraid that the possibilities of the Diesel engine did not come within the scope of the paper.

In reply to Mr. Lovesey, undoubtedly the output demanded from an engine affected the degree to which the mixture could be weakened while maintaining satisfactory operation. He thought that this was an aspect of the subject which would repay further investigation. He was interested to hear that Mr. Lovesey had found the exhaust valve temperature the limiting factor when weakening the mixture. This seemed in general agreement with the R.A.E. tests, which however were made with an air-cooled radial engine. The improvement due to the use of sodium-cooled valves was very striking, in the example quoted. The effect of water temperatures was also interesting, and was a strong argument in favour of evaporative cooling. The reduction of back pressure on the exhaust with increase of altitude was of course offset by the corresponding reduction of intake pressure.

He was interested to hear that Squadron-Leader Cole had found that improving the economy of engines did not necessarily lead to a decrease in the running time between overhauls, but might even cause an increase. Even a 5 per cent. reduction in fuel consumption was worth getting.

He quite agreed with Mr. Scott Hall's point about the difficulty in fitting flowmeters in many aircraft at testing establishments. The makers of large flying boats nearly always made provision now for fitting flowmeters, and he would like to see the practice extended to other types of aircraft.

In common with Flying-Officer Whittle, he had been surprised to find how few pilots realised the effect of speed on range, and he was obliged to him for his graphical illustration. He was glad, too, that Flying-Officer Whittle had emphasised the necessity for flying high in order to get both long range and high speed in still air. The converse, of course, was that when attempting duration records one should fly as low as possible.

The effect of superchargers on consumption was a somewhat controversial matter, but he was inclined to agree that, in general, the present type of supercharger was more likely to have an adverse than a favourable effect on the distribution.

He would like to say how much he had been impressed by the way in which the Range of Aircraft Panel, under the Chairmanship of Mr. Farren, had cleared the ground on the controversial subject of the effect of height on range, and had suggested an experimental line of attack.

He agreed with Mr. Farren that a flowmeter could be of great assistance in getting economy in routine flying, if intelligently used. He had replied to Major Green on the subject of mixture control calibration in terms of height.

The R.A.E. flowmeter is certainly a somewhat bulky instrument, but the fact remains that it is the only really satisfactory flowmeter so far produced. The Venturimeter was considered during the particularly comprehensive investi-

gation made when evolving the R.A.E. instrument. It is not satisfactory because it does not measure either the mass or the volume of fuel passing, but a combination of the two; and it has the disadvantage of having a square law scale. It is affected by viscosity, temperature and the presence of dissolved gases in the fuel.

In reply to Mr. Rodwell Banks, ordinary Service fuel was used in the flight tests described and in some of the bench tests, while on other bench tests the fuel contained a higher proportion of benzol.

He was sorry Mr. Banks had not given any indication as to what degree of difference in the consumption figures might be expected due to variations in the fuel supplied by different contractors to the same specification. The flight tests described covered a period of several months in each case, and it was probable that a change in the fuel contract occurred during the tests. No consistent differences between the consumptions obtained under similar conditions at the beginning and at the end of the tests were observed.

He was very glad that Mr. Rodwell Banks had contributed to the discussion, for he felt it was valuable to have the point of view of a fuel specialist.

In reply to Mr. H. L. Hall, he considered that the consumption curve of an aircraft at any height, and hence the minimum quantity of petrol required to fly a given distance, might be determined quite as accurately with a flowmeter as with a calibrated tank, and with a considerable saving in time. The fluctuations in flowmeter readings due to bumps are not large under atmospheric conditions suitable for measuring consumptions. He agreed that a flowmeter was valuable for seeing that a previously determined flow was maintained, but it was important to maintain level flight all the time.

On both the series of flight tests described, readings were obtained both with the flowmeter and with the small calibrated tank, and on the Venturi tests simultaneous readings by the two methods were obtained. Excellent agreement between the two methods was found.

He agreed that flowmeters are not always easy to instal, especially in multi-engined aircraft. On the other hand, accurate measurement of the consumption of a multi-engined aircraft by any other means is usually extremely difficult, and the flowmeters show at once if any engine is being run extravagantly. The mounting of flowmeters near the carburettors is certainly desirable, but not absolutely essential, and in multi-engined flying boats they are often mounted inside the hull.

The engine in the Venture was fitted with stub exhausts, that in the Stag with a collector ring and tail pipes, while, to the best of his knowledge, the engines tested on the bench had open exhausts.

Mr. Hall's experiences of the effect of intake temperature are very interesting, and confirm our own impressions.

He did not consider the term " specific fuel consumption " misleading, although it seemed to have misled Squadron-Leader Haythornthwaite. It may, of course, be expressed in any units, and the word " specific " is used in its usual engineering sense. " Ergogenic " may be more correct etymologically, but it is hardly likely to displace a term both more familiar and more euphonious.

Flight-Lieutenant SCROGGS said that he would attempt to deal generally with a few only of the many interesting points raised in the discussion.

The value of the investigations described seemed to him to lie chiefly in showing what improvements could be made if fuel were used economically, and the kind of carburettor characteristic required. It is not suggested, as some speakers seem to have understood, that all engines should be immediately run with 10 per cent. weak mixtures. Apart from the difficulty of controlling the

mixture strength accurately with the present instruments, the effect on the engine is not definitely established. At the same time the possible saving has been shown to be so large as to make this worth further investigation, while it seems probable that at *cruising speed*, which alone is of importance when considering maximum range, there is little or no deleterious effect from running on weak mixtures.

He agreed that the original object of interlinkage of the A.C. and the throttle was to prevent the engine cutting out when opened out after a long descent, but he did not think that it was always desirable that the A.C. should be kept shut on modern engines. Many engines, principally supercharged ones, in his experience, opened out better if the A.C. was left open, and he suggested that a recent forced landing by a friend of his might have been avoided if this had been done.

It is not suggested that 3 per cent. drop in r.p.m. necessarily represents the most economical mixture, but this is about as far as one can go in the air without irregular running and resultant vibration. The air intake temperature certainly affects this considerably.

He apologised to Mr. Dodson for having described an obsolete form of Claudel carburettor in his section of the paper, and agreed that the Type AVT 70G did not operate as described.

He agreed with Mr. Rodwell Banks' remarks. An improved fuel specification would not only enable it to be more economically used, but would permit certain improvements in engine design which might have an even greater effect.

It appears that air-cooled and water-cooled engines can attain about the same minimum fuel consumptions, but that the former are more susceptible to damage at the higher powers. Possibly the piston ring trouble mentioned by Major Green might be due to the absence of free petrol tending to prevent oxidation of the oil in the combustion chamber. Salt-cooled valves, as mentioned by Mr. Lovesey, may remedy the exhaust valve trouble.

In reply to Captain Swan, there is further evidence that advanced ignition is of greater benefit at reduced throttle openings, but tests on this matter are not yet completed.

In reply to Mr. H. L. Hall, the unserviceability of the Stag was due to its being an obsolete experimental type, and was in no way due to the engine, which was in excellent condition at the conclusion of the tests. The effect of the braiding on H.T. leads was, he believed, a capacity effect, and definitely weakened the spark energy. It was not only a source of possible conduction.

Squadron-Leader Cole's experiences are very interesting, and certainly seem to confirm their own results.

PROCEEDINGS

THIRD MEETING, SECOND HALF, 67TH SESSION

The Third Meeting of the Second Half of the 67th Session of the Royal Aeronautical Society was held in the Lecture Theatre of the Royal Society of Arts on Thursday, February 4th, 1932, when a paper on "The Organisation of Air Routes for Night Flying," by Dr. Rudolf Benkendorff, of Berlin, was read and discussed. Colonel The Master of Sempill (Past President of the Society) was in the Chair.

The CHAIRMAN: Dr. Benkendorff was a great authority on the organisation of air routes for night flying, and not only had he taken the trouble to prepare a paper to read before the Society, but he had travelled from Germany to England at a time when, due to the necessity for economy and other reasons, his department were very heavily overworked. The Society welcomed him cordially, and would ask him to convey its warmest greetings and thanks to Baron von Brandenburg, the Director of Civil Aviation in Germany, who had made all the arrangements for Dr. Benkendorff to present his paper. Dr. Benkendorff was in charge of one of the departments under Baron von Brandenburg, that department being concerned with matters concerning wireless, meteorology and night flying.

The German airway system had over a thousand miles of regularly organised routes available for night flying. It was true that, owing to the need for economy and for other reasons, these were not all used at night during the winter period, though they were so used during the summer. The question of night flying was of vital importance in Great Britain; its importance had been emphasised by Colonel F. C. Shelmerdine, the Director of Civil Aviation, and others of his department, and the fact that they had only a very short distance organised for night flying in this country was no fault of theirs. It was due to the need for economy, and so forth, and if the means were available there was no doubt that the department would be able to provide the system. The short distance from London to the coast was lit. There were facilities, though they were not complete, on the route from Egypt to Karachi, and he believed that they were being extended.

The Chairman apologised to the meeting on behalf of the President of the Society, Mr. C. R. Fairey, and of Colonel Shelmerdine, both of whom were suffering from influenza.

THE ORGANISATION OF AIR ROUTES FOR NIGHT FLYING

BY

DR. RUDOLF BENKENDORFF, BERLIN

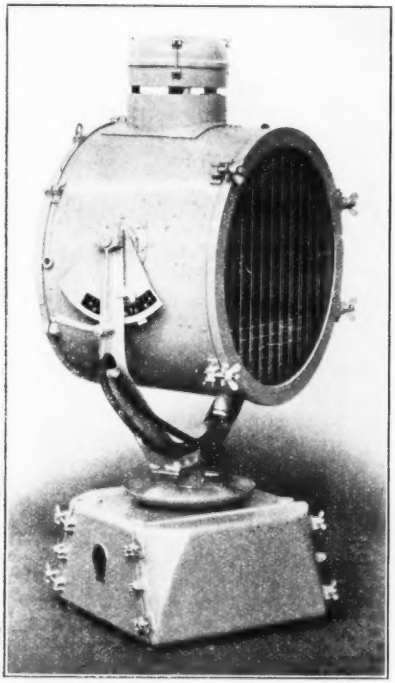
The operation of scheduled night flying presents two tasks to aviation:—

(1) The technical task of taking off from and landing on an aerodrome.
(2) The operation of the flight from one aerodrome to the other.

The first task presents no completely new problem, as sufficient experience was gained during the war. All that was necessary was to provide facilities which guaranteed regular traffic.

The second task was purely one of navigation. It had to be solved in accordance with the strict demands of maximum safety and maximum regularity of the service. The only means of navigation then available, the compass, was not sufficient for these requirements, and at night it was not possible to count on keeping on the course by observing objects on the ground.

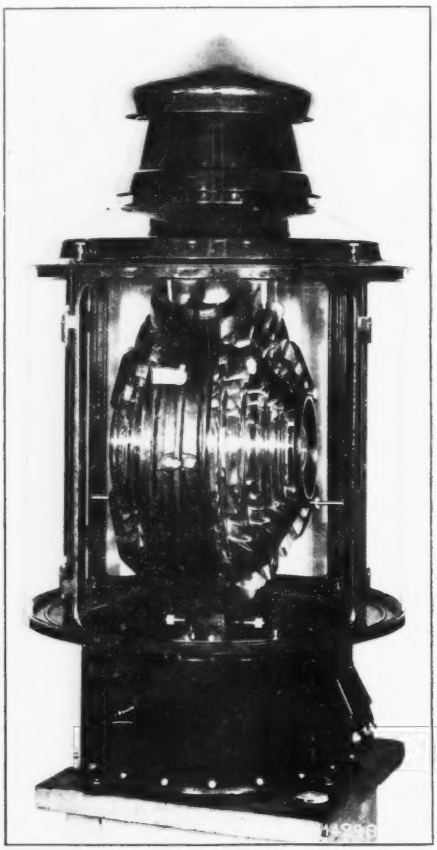
In order to show the direction taken by the development of navigation in night flying, and what ideas led to actual safety conditions in night flying, I will give a short survey of the development of the organisation of night flying in Germany from 1926 to 1931.



Rotary reflector beacon, 24½ inches diameter of the reflector, type Siemens-Schuckert.

Apart from the night flying experiments carried out in 1924 and 1925, which are unimportant for our subject, the first regular scheduled night air service for the transport of passengers, freight and mails was operated on the line from Berlin to Königsberg, in 1926. Multi-motor aircraft of the Junkers and Albatros types were employed. The aircraft were fitted with wireless equipment, and the wireless ground stations of Berlin, Danzig, and Königsberg were available for the airway, which is 425 miles long. It must be remembered that wireless direction finding did not exist at that time, and that it was not then possible to think of blind-flying for longer distances. If the necessary safety and regularity were to be attained airway lighting had to be instituted in order not to be solely dependent on the compass.

Starting with the idea of always keeping the right course, even when the visibility is bad, a close line of beacons was erected: principal airway beacons (revolving beacons) every nine miles, and intermediate beacons with a shorter range every three miles. In addition, emergency landing fields were prepared every 50 miles—with personnel to give traffic signals to the aircraft, send weather messages, and be ready to render assistance in case of a forced landing. The development of this night traffic is intimately associated with the name of Captain Köhl.



Rotary lens lantern, type D.L. 150 Pintsch.

Even then, there was no doubt that flying along such a close line of beacons when the visibility was bad kept the pilot within dangerous vicinity of the ground. But no other solution could be found at the time, if night air traffic was not to be abandoned altogether. Night traffic was the only form of civil aviation which gave promise of economic development, in view of Germany's situation in the heart of Europe.

The lighting of the line from Berlin to Hanover, which is 155 miles long, was built in 1928, in accordance with the same principles, with principal airway beacons every 17 miles and electric or gas intermediate beacons every three or four miles. In building this line the beacons were placed for the first time in a bee-line.

Ideas regarding the method of airway lighting underwent a fundamental change when blind-flying was introduced into civil aviation, and a network of direction-finding stations was erected for the purpose of giving position, direction and course to aircraft in flight by wireless.

Two technical developments which had a decisive effect on the organisation of night airways became available almost at the same time for utilisation in scheduled flying. The safety of night flying was thereby decidedly increased. The pilot was able to avoid the dangerous vicinity of the ground when the clouds were low and the visibility bad. Direction finding provided him with a safe means of navigation which supplemented the compass. Thereby the task of airway lighting was fundamentally changed in that it was limited. The following considerations arose at the time, considerations which still form the basis of airway lighting in Germany:—

If the atmospheric visibility diminishes to less than a distance of between three-quarters of a mile and one mile it is in the interest of safe flying not to fly by the beacons, but to fly blind at an altitude which excludes any collision with the ground or with the highest points in the neighbourhood of the air route. The aircraft can be steered to its destination with the help of the compass and direction-finding much more safely than can be done with the help of beacons.

Thus, airway lighting is only of importance for atmospheric visibility greater than from $\frac{3}{4}$-mile to one mile; its character had to be changed accordingly.

The following further consideration arose: The flash of a strong revolving beacon is visible from $1\frac{1}{2}$ miles under conditions of atmospheric visibility of one mile. If we reckon in squally weather with a maximum deflection of the aircraft to six degrees on either side of the course, a distance of 15 miles between the beacons is sufficient, when flying on the beacon line, to get in sight of the next beacon in every case.

In view of these considerations, all new lines of airway lighting were constructed in accordance with the following principles:—

(1) Revolving beacons at intervals of 15 miles.

(2) All beacons in a bee-line between the aerodromes.

(3) Only electric lighting, as gas lighting is not sufficiently intensive and too expensive in working.

Between 1929 and 1931 the following beacon lines were erected:—

(*a*) From Hanover to the Dutch frontier, in the direction of Amsterdam, distance 112 miles; branching off from it and avoiding the Ruhr industrial area owing to its hilly character and the prevailing bad visibility.

(*b*) Branch-line to Cologne and the Belgian frontier in the direction of Brussels, 145 miles.

(*c*) From Hanover to Fehmarn, in the direction of Copenhagen, 158 miles.

(*d*) From Berlin to Halle/Leipzig, 90 miles.

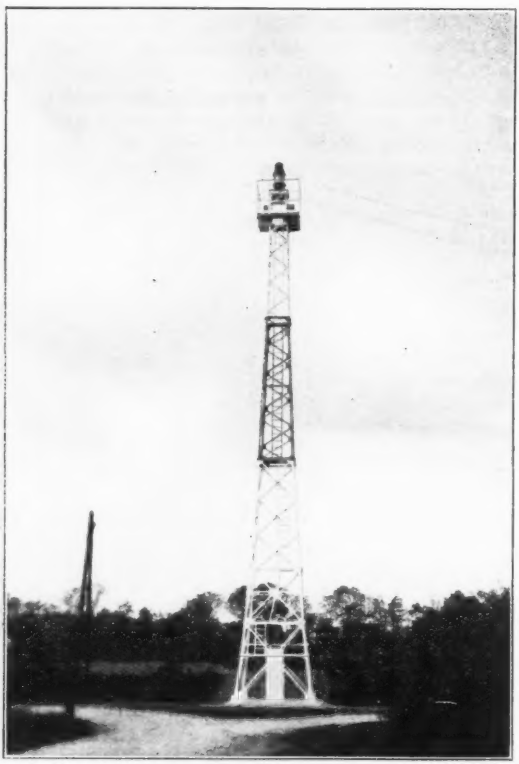
The intermediate beacons on the line from Berlin to Hanover were extinguished, and on the line from Berlin to Königsberg only the Neon intermediate beacons which are very cheap to work are still in use.

The total length of the lighted airways is 1,085 miles and is illuminated by 97 principal airway beacons and 38 intermediate beacons.

The characteristic of the beacons is uniform, being:

2.8 sec. dark period.
0.2 sec. flash.

3.0 sec. revolution.



Principal airway beacon.

The choice of characteristic was based on (1) bringing as much as possible of the light produced to the pilot's eye, and (2) adjusting the repetition of the flash so that the pilot has no difficulty in finding the light again. I will return to the characteristic when discussing the problems.

The following technical details of the lighting may be mentioned:—

The beacons are installed on iron masts from six to seven feet high. The following types are in use: Rotary reflector lights with a reflector 24½ inches in diameter and with rotary lens lanterns of which the concentric glasses are from 15 to 20½ inches in diameter. All lights have an automatic device for changing the lamps, which are from 1,000 to 1,500 Watts. Rotary reflector lights and rotary lens lanterns thus give a light of from 1,500,000 to 2,000,000 Hefner candle power, which represents a candle power of 400,000 Hefner candles for the pilot's eye, and a range of from 30 to 40 miles. The beacons are turned off and on by special automatic switches attached to each beacon. One electrician is in charge

of every 150 miles of the line, and it his duty to keep the beacons in order and put right breakdowns.

There are, in all, 14 ground direction-finding stations for the entire air service, of which those at Berlin, Hanover, Hamburg, Dortmund, Cologne, Erfurt, Stettin and Königsberg are available for night flying. The method employed is that the bearing of the mobile station is taken by the ground direction-finding stations on the aerodromes according to the minimum method. The Telefunken frame direction-finder is used. These 14 direction-finding stations are so distributed over Germany that they give favourable angles for position finding for every place in Germany. Experience shows, however, that aircraft ask for direction or course in most cases, and that position is only asked for from time to time for purposes of verification.

The difficulties which arose at first owing to the great deviations of the beam at sunset, night and dawn may be said to have been overcome. A practical method of direction-finding has been developed which gives the fixed bearing, if the bearing is taken in the first few seconds after the aircraft transmitter is switched on. No scientific explanation of this has yet been given.

Emergency landing places, which are about 500 yards in diameter, have also been erected on the night airways every 40 miles. All aerodromes for night flying and all emergency landing fields are provided with ceiling projectors, as it is of great importance for night flying to know the exact measured height of the base of the clouds.

The aerodromes used for scheduled night flying are all provided with the following equipment to insure safety in starting and landing:—

(1) An aerodrome beacon which either gives the characteristic of the aerodrome, or, what is better, a revolving beacon with an identification light giving the characteristic of the aerodrome.

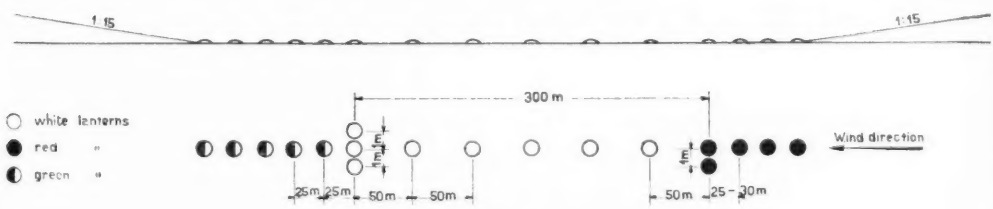
(2) Boundary lights, generally Neon tubes, at intervals of 100 yards.

(3) Red lamps on the obstructions.

(4) One or two illuminated wind indicators or T-shaped tubes.

(5) One ceiling projector.

On German aerodromes and emergency landing fields a line of stable lanterns with different coloured glasses is used to indicate the direction in which landings are to be made (see sketch). This arrangement is both simple and cheap, and has proved thoroughly effective. So far there has been no necessity to make use of flood lighting, which is expensive to instal and run. The use of stable lanterns has not led to any accidents occurring.



Landing-direction Lights.

The aviation weather service for night traffic is based on the same principles and methods as have proved effective for the safety of day traffic. The daylight arrangements are supplemented by the regular measurements of the height

of the clouds by means of ceiling projectors, and the measurement of humidity on the aerodromes and emergency landing places, in order to facilitate the fog forecast, which is of great importance for night flying. A special night staff of meteorologists is maintained on the aerodromes at Cologne, Hanover, Berlin and Königsberg.

It is unnecessary to go into details, as the weather and wireless services for aviation have been regulated by international agreement. The many years' work of the International Air Conferences have resulted in the adoption of fundamental lines of co-operation which are embodied in the Regulations for International Weather Service for Aviation and the Regulations for International Wireless Service for Aviation.

I need hardly mention that the safeguarding of night flying is still occupying the attention of experts. I should now like to touch briefly on the questions which, in the opinion of experts, are at present most pressing. In this connection I should like to quote the words of the late Sir Sefton Brancker, whose loss we all deeply deplore. During a discussion on the subject of airways lighting, he remarked: " We don't need any lighting, for we can't see it in bad weather and in good weather we don't need it." There is a good deal of truth in this remark, but I venture to think that it must be taken with a grain of salt. True, we can fly blind now, and direction-finding and the compass are good means of navigation. But it must not be forgotten that the direction-finding service may be interrupted or have breakdowns caused by atmospherics or thunderstorms. It must also not be forgotten that considerably less strain will be put on the nerves of the pilot if he can fly along a lighted airway when the visibility is good, a fact which must not be underestimated in the interests of the crew. For the minimum visibility of about one mile, airway lighting will always retain its importance.

An aircraft is not like a ship, which can slow up or even stop when there is any doubt about the navigating measures to be taken. Unfortunately, an airman must always know what course he has to take, and, in case of doubt, at once have all facilities in order to avoid making wrong decisions. The reasons which have led, and will still lead, us in Germany always to maintain good lighting of the airways are maximum safety for flight operations and minimum strain on the crew and material.

It is impossible yet to say whether beacon distances of 15 miles are the last word in wisdom. There are many people, even in Germany, who are in favour of greater distances, for instance, 20 and even 30 miles. But this must be decided on the basis of a thorough examination of the results of experience. This is the tragedy of all safeguarding services, not only in aviation, that their importance and efficiency cannot be proved by statistics. For, unfortunately, we cannot say how many accidents have been avoided by the use of the safeguarding services. Therefore, if all we have to go upon is experience, we ought rather to do a little more than a little less in the interest of safety, as there is a personal factor in all experience.

In the issue of " Aircraft Engineering " of October, 1931, I read in an article on Ground Lighting Equipment that airway beacons must be distinguished by their colour, strength and characteristic. We are of the opinion that all airway beacons must be white and have the same characteristic. In theory, it may seem very convenient that airway lighting should serve not only to give the direction or course, but also the position. These are ideas which seem to be derived from the practice adopted in marine and coast lighting, which cannot be adopted in aviation without objection. The aircraft moves at much greater speed, and the pilot's main business is the steering of the aircraft. He can only devote part of his attention, perhaps from 20 to 25 per cent., to observing the lighting. He cannot observe the direction and characteristic of the beacons at

leisure, as the naval officer does, for the line of beacons can only give him the direction—if he is not to be asked to do more than he possibly can. Mistakes in determining the characteristic will always have very serious consequences in aviation. The use of coloured glasses in airway beacons has the great disadvantage that it greatly decreases their range.

We have often discussed in Germany whether we ought to attach illuminated letters or figures, identification lights or course lights to the beacons, as has been done in the United States. It cannot be denied that these arrangements may have a certain value. So far we have dispensed with all such additional arrangements as they do not change the fundamental idea of the lighting, and their installation does not appear desirable to us until an international agreement has been arrived at on the subject.

The organisation of the safeguarding of night air routes is, in my opinion, to be regarded, not from the national, but from the international standpoint. The present night line from London to Berlin, for instance, which is flown in 6½ hours, passes over three or four countries. It cannot possibly increase the safety if the pilot encounters three different systems of lighting during the course of his flight. The air line, and not the State, must be regarded as the unit for which standards must be found.

The International Air Conferences have already laid down these standards for the wireless, and meteorological service for aviation. The International Aviation Lighting Committee has already done valuable pioneer work in the matter of standardising the technical terms, scientific physical research, and the treatment of questions concerning airway lighting. But practice must be decisive in these matters and utilise experience. It will be easier to arrive at a uniform point of view in this way, for practical airmen are more likely to agree than scientists.

The longer the delay in arriving at uniformity, the more difficult will it be to do so, for the question of the cost of changing existing lighting arrangements will always stand in the way.

A Vote of Thanks

The Chairman: He expressed to Dr. Benkendorff on behalf of every member of the Society their warmest thanks for having given an excellent exposé of the system developed in Germany to aid night flying, and assured him that it would be of the greatest use to us in this country. It would be appreciated particularly by Colonel Shelmerdine, Major Mealing and other officials of the Department of Civil Aviation.

(At this stage Colonel the Master of Sempill had to leave the meeting in order to attend another function, and Major Barlow (a Member of Council) occupied the Chair.)

Discussion

Major Mealing (of the Department of Civil Aviation): He had been asked by Colonel Shelmerdine to say that he had read the paper with the greatest interest. One thing that Colonel Shelmerdine had intended to do, had he been able to attend the meeting, was to apologise for the present airway lighting in this country, and when he (Major Mealing) had seen Dr. Benkendorff's comparison of the lighting in Germany and in this country he had felt rather ashamed. It must be remembered, however, that that lighting system was installed more than ten years ago; admittedly it was bad and had to be improved. Two different schemes of lighting for this country had been worked out, one of them being very ambitious and, in consequence, expensive—so expensive that it had had to be deferred. At the moment the department was working on a very simple but

effective scheme of lighting between Croydon and the coast, which scheme would be considered in relation to an auxiliary aerodrome for Croydon, which aerodrome would be available for day and night use in bad weather. That scheme should make night flying safe so far as the Continental services were concerned. He believed there were many people who did not realise that 75 per cent. of the organisation of a successful air service was on the ground; that was being borne out more and more every day, and Dr. Benkendorff had proved it conclusively. Aircraft could not fly regularly by night in bad weather without a proper ground organisation.

With regard to wireless or direction-finding services, Major Mealing mentioned the new type of radio beacon that was being erected at Croydon, and asked whether it was the intention to instal such a system in Germany.

Whilst he was in accord with Dr. Benkendorff in regard to most of the matters discussed in the paper, he disagreed in regard to one or two minor matters. Having landed at Berlin and at Croydon at night, he could not help feeling that they in this country were justified in going to the expense of providing the flood lights used there, in spite of the fact that Dr. Benkendorff had claimed that the system involving the use of storm lanterns was satisfactory. He personally had no doubt that they were right, and he even dared suggest that Dr. Benkendorff would be convinced some day that they were right.

After intimating that he would like to hear opinions with regard to the use of neon boundary lights, Major Mealing drew attention to Dr. Benkendorff's reference to an article published in "Aircraft Engineering" of October, 1931, in which it was stated that airway beacons must be distinguished by their colour, strength and characteristic. Dr. Benkendorff had stated that in the opinion of his department, all airway beacons must be white and must have the same characteristic. If he had continued to read the article referred to, which was admittedly a little ambiguous, he would have noted that their beacons were to be white and of the same character throughout; only by those means would night flying be simplified—as it must be. Therefore we were in complete accord with Dr. Benkendorff.

As Chairman of the British Aviation Lighting Committee, Major Mealing said that one of the objects of that Committee was to standardise equipment in this country. First, however, it must standardise terms, and then the equipment itself. He was glad that Dr. Benkendorff had emphasised the importance of the international aspect of flying, for there was no doubt whatever that they would make no progress at all in the matter of long-distance night flying from one country to another until the matter was tackled from the international point of view, so that the same system would obtain throughout the various countries. He assured Dr. Benkendorff that those responsible in this country were very keen indeed upon tackling the international aspect of the problem as soon as possible.

Colonel H. Burchall (Assistant General Manager, Imperial Airways Ltd.): He would prefer to speak as a taxpayer and as a potential passenger rather than in his business capacity, inasmuch as he was not in a position to expound the views of his Company.

From one point of view he was sorry that Great Britain had no definite scheduled night services, but from another point of view he was pleased. As a taxpayer he was glad that the Government's policy was that British civil aviation should be made to pay its way as soon as possible, and he believed no one would doubt that night flying was more expensive than day flying, and it was therefore necessary to determine whether the advantages of night flying outweighed the additional cost.

In this matter it became necessary to consider separately the short Continental routes and the long Empire routes. Taking the Continental routes first, it was evident that night flying served the greatest purpose when the distance covered

by the flight exceeded the distance that could be covered by train in the course of the night, *i.e.*, the distance must be at least 500 to 600 miles. Otherwise a night service was of little use for mails and freight and must rely on passenger traffic revenue alone. He doubted whether there were enough passengers prepared to fly at night to justify a night passenger service at present. Night flying over distances of 250 miles, for instance, was scarcely of use except in special circumstances which did not appear to exist in this country and probably not even between London and Paris.

The difference in the conditions surrounding night flying in this country on the one hand, and the United States and Germany, for example, on the other, was most marked. After flying a distance of under 100 miles to the coast, British machines flew over the sea and foreign territory, and on the main Continental routes British machines traversed more foreign than British territory. In Germany he believed that the reverse was the case, and it certainly was in the United States, and in consequence their night services could be carried out with simple co-operation between the operator and his own Government departments. It was important to bear the different conditions in mind when making comparisons.

Enthusiasts often urge that night services should be operated for mails only, but the wisdom of operating them depends on the loads available. Possibly in America and Germany adequate mail loads are available, but those who ought to know state that the bulk of British first class mail matter will not stand any surcharge at all for expedited delivery, while the American Postal Administration have in one year paid to their air mail operators 7,000,000 dollars more than they have received from their public. The American administration is now bringing pressure to bear upon the operators to make provision in the air mail machines for the carriage of passengers as well.

Taking now the long Empire routes, mixed loads of passengers, mail and freight are necessary to provide a sufficient total load to permit the employment of large aircraft having a low ton-mile cost. Colonel Burchall confessed that as a passenger his instinct would be to fly by day rather than by night, and even if he were assured by the best authority—the insurance underwriters—that night flying was just as safe as day flying, he would still prefer to travel by day, while if he were asked to fly by night as well as by day he would regard it as too strenuous except in the most urgent circumstances. His belief was that there were not enough passengers who found themselves in such circumstances to make a day and night service at present profitable.

It should not be overlooked, however, that the British services do, in fact, fly frequently by night, either finishing a journey after dark or starting before dawn, to cope with head winds, etc., and to maintain schedule. In due course, doubtless, more and more night flying will be done, first on the sections where no mountains have to be crossed and where fog is not prevalent and where no political difficulties are encountered. Unfortunately, the increase of cruising speeds by day and the operation of services by night produce conflicting requirements. For night flying the lowest reasonable landing speed is required, and with increase of cruising speed the landing speed inevitably goes up, and so in this as in all other engineering matters a compromise must be adopted.

Major Brackley (Air Superintendent, Imperial Airways, Ltd.): He agreed, in the main, with the efforts made by Dr. Benkendorff to secure standardisation of aerodrome lighting. Imperial Airways did a certain amount of night flying, mostly on the Indian route, but they were not fortunate enough to have aerodromes so well lit as were those in Germany. He was particularly interested in the problem of direction-finding at night, for a certain amount of night error had been experienced, and he asked for further information with regard to this matter.

The Chairman: Would Major Brackley give his views as to the desirability or otherwise of flood-lighting systems?

Major BRACKLEY : Personally he was not a great believer in flood lighting, and preferred the use of flares to storm lanterns or any other form of lighting.

Squadron-Leader NIGEL NORMAN (Airwork Ltd.) : It seemed to him that the very interesting organisation to which Dr. Benkendorff had referred was arranged particularly for the operation of scheduled services. He asked, however, whether it was considered that in the future pilots other than those engaged on regular services would wish to use the illuminated airways, and, if so, whether some of the conclusions mentioned in the paper might not be altered. If the expenditure on the organisation of night flying routes were to be justified, it seemed advisable so to organise those routes that they would be useful not only to pilots engaged on regular scheduled services, but other pilots as well. For instance, it might be advisable to instal beacons at shorter intervals than those adopted at present. Again, with regard to characteristics, he said that in America recently he had been very grateful for the fact that the beacons adjacent to the emergency landing fields had a green identification light as well as the revolving flashing light ; that practice had saved him trouble on one occasion.

Mr. C. B. COLLINS (Civil Aviation Dept., Air Ministry) : He strongly endorsed Squadron-Leader Norman's views on the problem as to whether the characteristics of beacons on an airway should be the same or whether there should be varying characteristics.

In the daytime it was common practice to follow railways, and in so far as these lay on the direct track they provided a simple and effective method of verifying positions from the air. Adherence to the correct track was an important factor in navigation, but the position along that track was sometimes equally important.

At night, the lighted airways would in time resemble a regular network of illuminated airways, and as these airways developed so would this network become more complicated. There was therefore the danger that pilots might not only follow the wrong lines, but also might not know their progress along any one line, particularly if bad weather had blotted out the route for some hours.

It was true that the best navigator had many methods at his command of checking his position. This, however, was no excuse for the ground organisation being incomplete in any one respect. Major Mealing, in opening the discussion, had hinted that the success of an air line rested on the efficiency of its ground organisation. Dr. Benkendorff had himself admitted that the wireless organisation comprised " some fourteen D.F. stations so distributed over Germany that they give favourable angles for position finding for every place in Germany." Yet, in discussing the lighting of routes the lecturer had expressed the opinion that because direction-finding provided the pilot with a safe means of navigation, which supplemented the compass, the task of airway lighting was fundamentally changed in that it was limited. By this he presumably meant position did not matter so far as lighting was concerned. It was difficult to follow this inconsistency. The average human being will always put more trust, and rightly so, in what he can see for himself rather than in what he is told by someone else. The navigating pilot will certainly always do so. The pilot should not therefore have to fall back on the W/T D.F. service whenever he wishes to ascertain position as distinct from track. The D.F. position should of course be available, but only for when visibility is bad or as a safety check on the visual position. This in itself tends to reduce wireless congestion. Any organisation in which one aid to navigation is made to supplement another instead of duplicating it, has no real factor of safety ; it is incomplete.

The lecturer's statement that a pilot could devote 20 to 25 per cent. of his time for observation of lighting seemed to support the argument for separate characteristics. Even with a luxurious spacing of beacons at intervals of fifteen miles, at a ground speed of 100 miles an hour, one beacon would be passed every

nine minutes. The maximum period of modern airway beacons did not exceed six seconds. Twelve seconds was therefore ample time in which to recognise their characteristics. This only represented 2.2 per cent. out of the 20 to 25 per cent. of the time said to be available for the purpose. If individual characteristics were provided for each beacon, they could at least be read by those who wanted them. They need not, however, be read by those (if any such persons exist) who were not concerned with their position.

In conclusion, they were looking forward to the day when aircraft will be able to fly by themselves with automatic controls. The pilot will take the aircraft off the aerodrome, set it on its course, then he will be free, in theory, to go to sleep. How, then, can the pilot tell, if the identity of individual beacons is enshrouded under a mask of Communism, when he wakes up towards the end of his journey, whether he has overslept or still has time for another forty winks?

Wing-Commander ALLEN (Department of Civil Aviation): Why did Dr. Benkendorff prefer storm lanterns to the flares used generally in the R.A.F. and on civil aerodromes in this country? From the point of view of economy of man-power alone, flares seemed preferable. It was a bigger undertaking to move numbers of these small lanterns about and re-space them when there were changes of wind, than to move five or six flares.

Captain ENTWISTLE: The references made to the conditions of atmospheric visibility under which such a system of night lighting could be used raised the question of the method used by the meteorological organisation for measuring visibility at night, and he suggested that the method used at present was not entirely suited to the needs of pilots who were flying at night along a lighted airway. In day flying the observer determined the farthest of a series of objects, spaced at fixed distances, which was visible; at night, however, he estimated the visibility to the best of his ability, according to daylight standards. They would have to change this method for one more suited to the needs of night flying, because obviously such a system was meaningless from the point of view of the pilot. The pilot wanted to know whether or not he would be able to see a certain beacon at a certain distance. As a matter of fact, the problem of observing visibility during the night was being considered, not only nationally but internationally, by the Meteorological Commission of the International Air Conference, to which Dr. Benkendorff had referred in the paper.

Captain Entwistle endorsed Major Mealing's remarks concerning the international character of the various arrangements for air routes; as Dr. Benkendorff had indicated, in regard to meteorology and wireless very complete agreement had been reached. If anything were necessary to prove that they in this country were putting the international aspect before the national in this matter, it was that since last November all meteorological information supplied to pilots at Croydon, whether they were British or foreign pilots, was given in metric units—cloud height in metres and visibility in kilometres.

Commenting on the remarks of Colonel Burchall as to night versus day flying, he said that in these islands, and particularly on the routes between Croydon and the Continent, one question which should be considered in determining whether or not night flying was advisable was the average weather conditions at night as compared with day flying conditions. He considered that there was a great deal to be said for night flying, particularly in winter, and he was quite sure that a properly organised service could be maintained with as good regularity as a daytime service during that part of the year. The same remarks would apply also in summer, of course, but it seemed to him that fact had not been given sufficient attention in the consideration of night flying. Further, from the point of view of the passenger, on the average, the atmospheric conditions were much steadier, *i.e.*, there was less turbulence and consequently more comfort during the night than during the day.

Captain W. L. Hope (Air Taxis Ltd.): Wireless was essential for night flying, and any pilot who took off and just "barged" across a country on a bearing, without being in direct touch with the ground, was asking for trouble. Having experienced a certain amount of night flying, he said that in nine cases out of ten one really did not know where one was, and without the aid of wireless one was just chancing one's luck. The universal standardisation of systems, he agreed, was very necessary. He was afraid, however, that many experiments would have to be carried out yet in connection with the lighting of aerodromes; the use of flares of the paraffin type was rather dangerous, because a machine might twist round when landing, and if it came up against one of these flares it would soon go up in a cloud of smoke.

Colonel Gold (Meteorological Office): He was impressed by the cleverness of Dr. Benkendorff, for towards the bottom of the last page of the paper there was a sentence which was such that if one disagreed with him as a scientist one proved the truth of his remarks, whereas if one disagreed with him as a practical man one proved that one was not a practical man. Colonel Gold added that he did not think he had seen, in the course of a long experience, a more clever introduction of a provocative sentence. With regard to ceiling lights, he asked how high it was necessary to have the ceiling light work, and said he believed Dr. Benkendorff had stated that up to about 5,000ft., *i.e.*, 1,500 metres, was the practical limit. Again, he asked what candle-power was found to be necessary in the ceiling lights for cloud observations. Of course, such lights were used only for short periods, but the cost of the lamp depended on the candle-power, and cost was an important factor. With regard to the problem of visibility, he pointed out that the distance at which a beacon was visible depended partly on the candle-power of that beacon, and not merely upon the amount of obscuring matter in the atmosphere. Therefore the problem would not be solved entirely by merely giving the practical pilot the distance at which a light was visible; one doubted, indeed, if it was practicable to give the pilot the distance at which a particular beacon was visible to him, because he would be viewing the beacon from a height, whereas ordinarily the degree of visibility would be determined at ground-level.

Finally, Colonel Gold expressed his appreciation of Dr. Benkendorff's work in promoting international organisation in meteorology, and was glad to see that he had taken the meteorological scheme as a model for organisation in other directions. It had been mainly the work of scientists, in spite of the statement in the paper.

Captain Furnival (Marconi Co.): Could Dr. Benkendorff give further information concerning the method he had mentioned for the avoidance of night errors on the German direction-finding stations? In this country a good deal of work had been done with a view to discovering a satisfactory means of avoiding night errors, and they had managed to obtain a satisfactory solution by the method of screening the horizontal portions of the direction-finding aerials.

Mr. M. L. Bramson (*Fellow and Member*): Was the vertical angle—he did not mean its inclination to the horizontal, but the cone angle of the beam—the same as the horizontal spread? He gathered that the latter was about 24 degrees, seeing that there was a flash of one-fifth of a second, and that one revolution took three seconds. It appeared that the vertical angle was the same, but it would be interesting to know whether, from practical experience, there appeared to be any reason to alter that, because there would presumably be no difficulty in producing a cone of elliptical section.

Discussing Colonel Burchall's remarks concerning the merits of day and night flying, Mr. Bramson said, with great respect, that he disagreed. One found, when discussing the merits of flying as against other means of transport, that people wanted to use aircraft for business purposes, but that on innumerable

occasions they could not save the time they wanted to save because they could not fly at night. It was quite obvious that for long journeys, *i.e.*, journeys longer than those which could be made by train in the course of a night, night flying would pay. But, surely it would also be worth while for a man to be able to do business in London during the day, to leave at 8 p.m. for Paris, in winter or in summer, arriving there at about 10.30 p.m., and then, after a night's sleep, do a day's business there.

Finally, commenting on the remark that pilots sometimes descended to such low altitudes that they could read the names of railway stations, Mr. Bramson expressed the hope that pilots would not in general stoop so low as to follow railway lines when they could do otherwise.

Reply to Discussion

Dr. Benkendorff : The installation of radio-beacons was quite a good scheme for single routes, but the conditions were quite different from those obtained when one had to deal with a network of routes. One air route only leads from Croydon to the Continent, and therefore a radio-beacon at Croydon may be useful. In Germany and in Central Europe, however, there is a network of air-lines, so that direction-finding service is operated not by beacons but by frame stations, which give favourable angles for position-finding for every place. Another factor to be borne in mind was that the southern part of Germany was mountainous and during daytime aeroplanes had to choose different routes according to weather conditions. It was better, therefore, to have a direction-finding service with frame-stations which could give direction, course *and* position. In the American service, where the pilot only knew that he was on the right course but did not know his position at any given moment, some difficulties will arise as the lines increase.

Mr. Collins noted that both direction-finding and lighting had to give direction and position to the pilot. He agreed, especially regarding aeroplanes not fitted with wireless. But, as mentioned in the lecture, only the addition of illuminated letters or figures to the airway beacons will have some value. The introduction of special characteristics for each beacon can have serious consequences in aviation. A private pilot, for instance, finding or crossing a lighted airway will have to observe firstly the characteristic of the beacon in sight—not easy at a speed of 100 miles per hour—and secondly to find the position represented by this beacon in a volume, not too small. The installation of additional arrangements appears desirable until an international agreement has been arrived at on the subject. It was always the view in Germany that it is of no use developing a lighting service and a wireless service separately; they were both provided for the one purpose of guiding aeroplanes, and there is one department in Germany which develops the two together. Dealing with Major Mealing's reference to the article published in "Aircraft Engineering" of October, 1931, Dr. Benkendorff said he could not decide exactly what was in the mind of the writer. The latter had laid down principles, but later he had made statements which were not in accordance with those principles. After reading the principles and the following statements, he (Dr. Benkendorff) had decided to regard the principles laid down as representing the views of the writer.

The opinion expressed by Colonel H. Burchall as to passenger transport and the carriage of mails and freight was interesting. In Germany there is passenger transport from Berlin to Königsberg, and mail transport from Berlin to the West. Experience must be gained before deciding on future policy. With regard to the flood lighting of aerodromes, he (Dr. Benkendorff) agreed that it was better than the use of storm lanterns. There is one matter of importance in connection with flood lighting as shadows occur if the surface of the aerodrome is not completely flat. The flood lighting on Dutch aerodromes therefore is very fine.

The remarks of Colonel Gold and Captain Entwistle are interesting. No method of measuring visibility at night is yet developed. Experiments will be made measuring the light-force of one or two determined lamps on an aerodrome by a photometric method, to get values of absorption and divergence, fundamental values for the visibility of airway beacons, which alone is interesting to the pilot. The objection of Colonel Gold that the pilot views the beacon from a height is right. But day visibility is given too by ground observations. We cannot overcome this inconvenience. The influence of the candle-power of the beacon is not of great percentage.

In ceiling projectors with a limit of 5,000ft. lamps of 12-volt, 100-watt, 150,000 Hefner-candles are used. The ceiling-projector type Pintsch with a practical limit of 10,000ft. has lamps of 12-volt, 250-watt, 2,500,000 Hefner-candles.

The problem of the deflection of the radio-beam had been studied very earnestly and a practical method of overcoming the difficulties had been found, as stated in the paper. It might be said that this method was found by chance. One of the operators remarked one day that his bearing did not change when it was taken in the first few seconds after the aeroplane transmitter was switched on. This repeated two or three times, gave sufficient fixed bearings. It was said that from the scientific point of view it was not possible to do what was claimed to have been done. But his attitude was that it was sufficient to get the right beam and that it was for the scientific people to find the explanation. At any rate, the pilots were satisfied with the present system. The Adcock method is no doubt of great value and it is being examined by German authorities.

Concerning the remarks of Mr. Bramson, I can note that German beacons have a flash of one-tenth second, which corresponds to a horizontal cone-angle of the beam of 12 degrees, not 24 degrees as stated. Such a short flash brings more light, more candle-power to the pilot's eye than a longer one. The latter produces a greater cone-angle but less light. The vertical cone-angle is only four degrees. Small light intensity is given in spite of this from 4-30 degrees (vertical), which is sufficient when flying in bad visibility by compass or direction-finding to observe the beacon. In German night air-service a flying altitude of about 900-3,000ft. is the general rule.

Dr. Benkendorff discussed the general question as to whether or not the installation of lighting facility on airways was too expensive from the point of view of the taxpayer. One could not say definitely, of course, that the provision of the lighting and wireless service had been the means of preventing a crash in any particular case. But it could be assumed that the services did prevent crashes. The cost of a crash of one three-engined aeroplane will be sufficient to cover the expenses of nearly a one-year operation of the lighting service in Germany.

Four hundred thousand Hefner-candles coming to the pilot's eye represents the difference—light produced by the lamp from the losses by the glass, the optic, the time of the flash, the age of the lamp and dirt and dust on the glass parts of the beacon. This figure is gained from the calculation of Mr. Bram van Vlooten and by experience.

Comparing neon tubes and red electric lights for boundary purposes, neon tubes are about fifty per cent. more expensive in installation but much cheaper in operation than any other electric light source.

Captain C. Ward (Chance Brothers) (*communicated*): Dr. Benkendorff mentioned that intermediate beacons with a longer range were installed every three miles. One would imagine he meant a "shorter range," the main route beacons being the more powerful of the two types.

In a country like Germany, where overhead power lines carrying electric current are widely spread, the installation of electric beacons may be justified on the score of economy. There are, however, many countries where a choice must

be made between an automatic generating set for electric light and an unattended acetylene beacon. Is it quite correct, therefore, to state that gas lighting is not sufficiently intensive and too expensive to work? It may be the simplest and cheapest of the alternatives when current from the mains or overhead lines is not available.

It would be interesting to know what Dr. Benkendorff meant when stating that the choice of characteristic for a route beacon was based on bringing as much as possible of the light produced to the pilot's eye. In the succeeding paragraph a reference is made to 400,000 Hefner-candles as that which was directed towards the pilot's eye at a range of 30-40 miles. It is not clear as to how this theoretical figure is calculated and what particular significance it has.

What special merit have neon tubes when used as boundary lights, bearing in mind the expense of their installation?

Dr. Benkendorff admitted in his answer to the discussion that properly designed flood lights are superior to " storm lanterns " if the surface of the aerodrome is such that no hard shadows are cast. Surely an aerodrome surface should be flat, and if it is not so, there are the alternatives of levelling it or providing a sufficient number of flood lights around its boundary so that two or more can be in use at one time, thus avoiding shadows to a considerable extent. This latter system is followed in Holland, though at the aerodromes where he had seen it in operation the individual flood lights are not powerful enough to illuminate the whole of the surface required by a pilot when making his landing.

Dr. Benkendorff refers to the fact that considerably less strain is put on the nerves of the pilot if he can fly along a lighted airway when the visibility is good. Surely the lessening of strain on a pilot's nerves is even more important when he is making his landing. What is the point in providing the pilot with an elaborate instrument board, wireless aids to navigation and an expensive air-route lighting system, if you allow him, at the end of, possibly, a long and tiring flight, to make his landing in the dark? If a good flood-lighting system has been installed, there is no excuse for a bad landing—or should he say a heavy landing?—which is the cause of so many minor accidents and of increased wear and tear on the machine. Professional pilots, of course, will make good landings as a rule with the aid of " storm lanterns " or flares, but their anxiety would be decreased considerably if they could see the ground on which they were landing and be quite certain that no obstacles are in their path. Furthermore, a good flood-lighting system will illuminate the boundary on the far side, which is useful in case a pilot overshoots the aerodrome.

If expense is no object, the surface of an aerodrome should be illuminated so brilliantly that it approximates to daylight conditions, and therefore maximum safety can be achieved on any aerodrome only by providing as much lighting ground as possible within reasonable limits of cost.

Although he had been contemplating only one lighted air route, that from London to the Continent, there will be a network of such routes within the boundaries of the British Isles in course of time, and therefore a decision as to whether beacons on any particular route should be distinguished from those on any other route is most important.

He suggested that Colonel Burchall had overlooked the fact that the air route from the coast to London is the final stage of many routes extending from the farthest points of Europe, Asia and Africa. If one considers civil aviation as an international affair, lighting will be required on all air routes through every country. In order to maintain regular services throughout the day and night, it must be possible to start or finish any journey during the hours of darkness, if connections to or from far-distant places make it necessary. Passengers are not afraid to travel by train, car or ship at night and therefore it seems a little unnecessary to alarm them about night air travel when there are no statistics to

show that it is more dangerous than that by day. In actual fact, military machines flying at night during the late war were less subject to forced landings than those operating during the day. The weather at night is, on an average basis, calmer and the air is more free from fog than during the daytime. Ground organisation for night flying must precede the establishment of night air services for passengers and routes should be well proved by means of services for mails and freight before they are thrown open for passenger traffic.

With regard to the comparison between "storm lanterns" and "money" flares, there seems to be little distinction except that there are more lanterns to move than flares. In the case of the flares, these are definitely dangerous if a machine should pass over one at slow speed or come to rest with a flare under a combustible part of the structure. Both flares and lanterns are difficult to set out in the correct direction for landing, it being impossible to show any small change in wind direction. If the wind alters its direction appreciably, this means that labour must be employed to alter the line of the flares and there is always the danger that a wheelbarrow or some other obstacle may be left on the aerodrome after the process of setting out has been completed. There is no doubt that some pilots are in favour of flares of some kind because the flood lighting at many aerodromes is not satisfactory owing to the inequalities of the surface causing shadows referred to by Dr. Benkendorff. This will be remedied in course of time, either by levelling the ground or by installing a number of flood lights so that their beams overlap.

The point made by Squadron-Leader Norman that aerodromes and routes should be so equipped that pilots other than those engaged on regular night services could use them with confidence is most important. Coastal lighting has been established throughout the world for the benefit of those navigating ships of all types, and the same policy must be followed eventually with air lighting.